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## Visualisation of inshore marine water depth data

Karen Powell  
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# **Visualisation of Inshore Marine Water Depth Data**

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by

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**A Project**

**Submitted to the Faculty of Science and Technology  
Edith Cowan University  
Perth, Western Australia**

**Principal Supervisor : Dr James Cooper**

**Submission Date : 18/02/1994**

**In partial fulfilment of the requirements for the degree of  
Bachelor of Applied Science (Information Science)  
Honours**

**I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.**

### Abstract

The literature review performed as part of this Project concentrated on two objectives. The first objective was the identification of techniques applicable to the visualisation of the inshore marine water depth data obtained from the Department of Marine & Harbours (M&H). The second objective involved examining how colour is best used within data visualisation.

The experimentation investigated a simple method for interpreting movement between depth surveys undertaken by M&H. Although it achieved the objective of creating a longer and smoother animation, it was concluded that the movement of the harbour floor was not accurately represented.

The Project applied an optical flow algorithm, originating from computer vision, to perform analysis of motion of material on the harbour floor. The output from the algorithm is a map that shows the motion (magnitude and direction) of the harbour floor in such a way that would allow M&H to quantitatively measure the changes in the harbour, as well as create a static image visualising the changes that occur from survey to survey.

Finally, we propose an algorithm to interpolate depth data between surveys. This is based on using the derived optical flow velocities to perform a morphing operation.

## Acknowledgements

The two people I would like to thank the most are my parents, David and Jeanne Powell, for their unstinting support, encouragement and understanding over *all* my years of study. I've finished!?

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## **Table of Contents**

Topic	Page
Declaration	ii
Abstract	iii
Acknowledgments	iv
1. Introduction	1
1.1 Background	1
1.1.1 The visualisation process	1
1.1.2 What is data visualisation?	2
1.1.3 Computers and data visualisation	3
1.1.4 Benefits of data visualisation	3
1.1.5 Aspects of data visualisation	4
1.2 The purpose of the study	4
1.3 Research questions	6
1.4 Project layout	6
2. Review of Literature	7
2.1 Introduction to data visualisation	7
2.1.1 Explanation of terms	7
2.2 Perception of depth	8
2.3 Design theory	9
2.3.1 Principles of graphic design	9
2.3.2 Methods used in graphic production	9
2.3.3 Objectives of graphic design	11
2.4 Cartography	12
2.5 Data visualisation	12
2.5.1 Introduction	12
2.5.2 Three-dimensional image creation	14
2.5.3 Two-dimensional image representation	14
2.5.4 Isolines and colour	17
2.6 Other techniques used in data visualisation	18
2.7 Graphic techniques used to indicate depth	19
2.7.1 Introduction	19
2.7.2 Types of projection	20
2.7.3 Other forms of depth indication	22



2.8	Colour	24
2.8.1	Introduction	24
2.8.2	Perception of colour	24
2.8.3	Suggestions on the use of colour	25
2.8.4	Conclusion	26
2.9	Choice of visualisation or graphic technique	27
2.9.1	Interpretation of graphics	27
2.9.2	Limitations of techniques	27
2.9.3	Call for standards	28
2.10	Interpolation techniques	29
2.11	Motion analysis	30
3.	Method of Investigation	33
3.1	Resource description	33
3.1.1	Data	33
3.1.2	Hardware and software	33
3.2	Current visualisation techniques	33
3.3	Motion analysis algorithm	34
3.4	Experimentation conducted	35
3.4.1	Preprocessing	36
3.4.2	Interpolation to create new images	37
3.4.3	Motion analysis via optical flow	38
4	Results	40
4.1	Results of experimentation	40
4.1.1	Interpolation results	40
4.1.2	Motion analysis	41
5	Conclusions and future directions	43
5.1	Summary of literature review	43
5.2	Conclusions draw from experimentation	44
5.2.1	Interpolation	44
5.2.2	Motion analysis	45
5.3	Future direction for project's experimentation	45
5.3.1	Improvements to optical flow algorithm	46
5.3.2	Improvements in data (sampling)	46
5.3.3	Improvements of experimentation programs	46
5.3.4	Proposed experimentation	47
5.3.5	Implementation concerns	48

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6	References	50
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Appendices

A	Description of brightness images representing the 1986 to 1992 depth values of Cambridge Gulf (Wyndham) harbour (Figure 11).	55
B	Description of brightness images representing depth differences between the 1986 and 1987, 1986 and 1988, .. 1986 and 1992 surveys of Cambridge Gulf (Wyndham) harbour (Figure 12).	63
C	Description of brightness images of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour for years 1986 to 1992 (Figure 13).	70
D	Description of needle diagrams showing 1986 to 1987, 1987 to 1988, .. 1991 to 1992 optical flow superimposed over the 1986, 1987, .. 1991 brightness images from Figure 13 (Figure 14).	78

### **Table of Figures**

Description	Page
Figure 1. Two possible visualisations showing the hierarchy and relationships within data.	10
Figure 2. Visualisation categories.	13
Figure 3. Object's surface depicted by lines of constant $x$ .	18
Figure 4. Parallel projection.	20
Figure 5. Perspective projection.	21
Figure 6. Necker's cube.	23
Figure 7. The Sobel operators.	39
Figure 8. Visualisation of a feature.	40
Figure 9. Two depth images, with darker indicating deeper	41
Figure 10. Needle diagram of optical flow between Survey 1 and Survey 2.	42

### **Table of Tables**

Description	Page
Table 1. Depth cues leading to three-dimensional perception.	8

## Chapter 1. Introduction

### 1.1 Background

#### 1.1.1 The visualisation process

As humans, our primary sense is vision and, as such, much of our understanding of our surrounding environment is visual in nature.

Visualisation is the process of applying this visual understanding to our environment, a process which most people apply in everyday life. Areas of use range from spiritual goals, healing of the body, sport, and the attaining of goals, to daydreaming, hallucinations and visions (Samuels & Samuels, 1975). Described as a "form of communication that transcends application and technological boundaries" (Defanti, Brown & McCormick, 1989), it is an important technique used to understand, remember and communicate concepts and information.

According to Clark in his foreword in Earnshaw & Wiseman (1992),

"Visualization [sic] has been the cornerstone of scientific progress throughout history. . . . Newton visualized [sic] the effect of gravitational force fields in three-dimensional space acting on a center [sic] of mass. And Einstein visualized [sic] the geometric effects of objects in relative uniform and accelerated motion, with the speed of light a constant, time part of space, and acceleration indistinguishable from gravity. Virtually all comprehension in science, technology and even art calls on our ability to visualize [sic]. In fact, the ability to visualize [sic] is almost

synonymous with understanding. We have all used the expression "I see" to mean "I understand".

### **1.1.2 What is data visualisation?**

Data visualisation, also known as scientific visualisation, is a process that translates raw data (scientific data objects), obtained through simulation or empirical measurement, into a graphical representation (graphical data objects) or visual image (Haber & McNabb, 1990; Hibbard, Dyer & Paul, 1992). According to Emmett (1992) it "provides the means for giving shape, color [sic], dimension to qualitative, quantitative, and single- and multi-parameter . . . data that might otherwise remain hopelessly abstract." The data visualisation process has three phases - data enrichment or enhancement, visualisation mapping and rendering.

The first phase, data enrichment or enhancement, operates on the raw data and produces the data to be visualised. The process may involve reducing noise, and the addition, removal or derivation of values. Noise is random fluctuations in the measured value from the true value. The second phase, visualisation mapping, constructs an "abstract visualization [sic] object" (AVO) from the results of the first phase. The AVO is the object within the visualisation software that is used to represent the data. The final phase, rendering, creates a displayable image by operating on the AVO (Haber & McNabb, 1990).

Data visualisation is not a new process, available only since the introduction of computers. For years people have been representing real-world (N-dimensional) data in a pictorial form on a two-dimensional surface. For example, cartographers make maps of the earth's surface; architects make

plans of buildings; artists create landscapes and portraits; and chemists draw molecular structures of compounds.

### **1.1.3 Computers and data visualisation**

The use of computers for visualisation purposes has greatly expanded over the last five years due to two major factors. Firstly, computer hardware capabilities have increased, whilst prices have decreased, so that more people now have access to computers and associated graphics hardware. The modern computer has increased speed, added memory (RAM and disk) and improved graphics capabilities. The display devices, with better resolution, colour depth and built-in memory, provide faster and clearer graphical displays (Earnshaw & Wiseman, 1992; Firebaugh, 1993; Fuchs, Levoy & Pizer, 1989; Gantz, 1992; Tukey, 1990). Secondly, computers are being used to store ever greater amounts of data. One source of such data is research and experimentation, using simulations and models of increasing complexity and realism. Another source is remote sensing. This larger volume of data has led to a corresponding increase in the required speed and ease with which such data needs to be processed (Defanti et al., 1989; Feeney, 1991; Firebaugh, 1993; Gantz, 1992; Haber & McNabb, 1990; Helman & Hesselink, 1989; Nielson & Shriver, 1990).

### **1.1.4 Benefits of data visualisation**

An effective way to describe, explore and summarise data is to look at the images formed by the data using computer-based visualisation techniques (Tufte, 1983, p. 9). Data visualisation is a powerful process as "pictures have inherent power to convey complex information" (Tukey, 1990). This is due to pictures effectively exploiting the human visual system's ability to recognise

spatial structure and patterns (Defanti et al., 1989; Foley, van Dam, Feiner & Hughes, 1991, p.3; Robertson, 1992).

#### **1.1.5 Aspects of data visualisation**

Data visualisation is a sophisticated tool for scientific research and investigation. It encompasses aspects of previously independent, more established fields, such as: computer graphics, image processing, computer vision, geometric modelling, approximation theory, signal processing, cognitive science, user interface design, perceptual psychology, applied mathematics, computer aided design and numerical analysis. All these fields use analogous tools. Users can quickly and easily identify the salient features of multi-dimensional data using data visualisation. Without the resulting images, this identification would be improbable or, at least, more difficult (Earnshaw & Wiseman, 1992, p.6; Haber & McNabb, 1990; Nielson & Shriver, 1990).

### **1.2      *The purpose of the study***

The Marine and Harbour Department of Western Australia (M&H) undertakes depth measurement surveys for each harbour under its jurisdiction, once or twice per year. These surveys generate a string of positions and depth measurements that follow the path of the survey boat as it criss-crosses the harbour. The raw data is adjusted to take into account the height of the tide, and then interpolation is performed to create a square grid using a least squares algorithm developed at M&H. This grid provides a raster representation of the surface the harbour floor.

Dredging of harbour channels occurs when they are determined to be too shallow. The survey process is repeated to ensure that the dredging

operation was completely successful. This process ensures that all channels in the harbour are of sufficient depth to allow passage of marine traffic.

M&H has developed its own set of standard maps to portray depth data. The common components of these are contours linking points of equal depth and colour to highlight and differentiate depth values. In order to make dredging decisions they need to understand how the shape of the harbour floor is changing.

One of their first methods for performing this motion analysis was by the use of difference maps. The values represented on this type of map are the changes in depth between two consecutive surveys (with points of zero difference being drawn as a contour). Although difference maps accurately represent the changes of depth between surveys, this form of motion analysis is restrictive. For example, analysis of the structure and movement of the harbour floor requires an experienced eye and much patience.

The current form of motion analysis is the animation of a series of solid colour maps. A solid colour map has each point represented by a colour, and each colour represents a range of depth values.

The purpose of this study is to identify appropriate visual representation techniques to display the depth measurement data from M&H's surveys, improve the efficiency of existing analyses and allow new and different analyses to be performed on the resulting images. Attention is focused on techniques that allow the analyst to determine both the direction and magnitude of the harbour floor movement. This will lead to improved understanding of such movements, which can be translated into economic benefit through better planning of dredging operations. The study will also investigate interpolation methods for generating the data between the surveys.



### **1.3      *Research questions***

The questions addressed during this study are:

- What various methods and techniques within data visualisation can be used to represent N-dimensional data on a two-dimensional plane?
- How is colour best utilised in visual representations?
- What methods and techniques can be used to interpolate the problem domain data for the periods between the surveys?
- Which of the identified methods and techniques allow for new analyses on the times-series' data produced by M&H's surveys?

### **1.4      *Project layout***

Chapter 2 contains a literature review of material examined in order to answer the research questions. Chapter 3 contains a description of the project's data (courtesy of M&H), and of the experimentation conducted.

The experimentation concentrated on techniques to determine harbour floor movement and to produce 'in-between' frames for animation of the data.

Chapter 4 contains the results of the experimentation. Chapter 5 contains the conclusion and future directions.

## **Chapter 2. Review of literature**

### **2.1 *Introduction to data visualisation***

#### **2.1.1 Explanation of terms**

The world consists of a multitude of data sources. These are measured and modelled, but difficulty occurs when we attempt to visually represent them. These data sources are referred to by different authors as multi-variate, in the domain of statistics (Tufté, 1990), multi-banded, in GIS and engineering, or multi-dimensional in the visualisation community (Crawford & Fall, 1990). Data visualisation is used to create images of a variety of data types. The technique used to visualise the data is dependent on the type of data and the form of analysis to be performed.

The data used for this project has three variables: an easting, a northing and a depth. This corresponds to a surface in three dimensions. The data format can also be described as two-dimensional, single-banded, since there is a single value for each position in the scene. The following chapter concentrates on the techniques for visualising this type of data.

Depth, the third spatial dimension, is the difficult dimension to visualise as available technology usually provides only a two-dimensional viewing surface. Before exploring computer implemented solutions we need to examine how the human vision system perceives depth. Some understanding of this perception should help us to better represent depth within these two dimensions, creating a more realistic image.

## 2.2 *Perception of depth*

Three-dimensional perception is achieved by adding cues to, or identifying cues within, the two-dimensional retinal image(s) (Braunstein, 1976). Depth cues can be categorised into monocular and binocular cues (see Table 1) (Braunstein, 1976; Gibson, 1979; Rosinski, 1977; Speoher & Lehmkuhle, 1982).

Monocular cues	
linear perspective	parallel lines or edges converge with distance
apparent size	object's size decreases with distance
interposition	occlusion of objects indicates relative spatial relationship
light and shade	object's brightness decreases with distance
aerial perspective	object's detail decreases with distance
accommodation	change in the shape of the eye's lens required to bring the object into focus
motion parallax	relative directions and velocities of movement indicate depths of moving objects
texture gradients	surface density increases with distance
Binocular cues	
binocular disparity	difference in retinal images due to the separation of eyes
convergence	eye movement needed to maintain the object in the centre of the view

Table 1. Depth cues leading to three-dimensional perception.

## **2.3      *Design theory***

### **2.3.1      Principles of graphic design**

The five design principles for data graphics presented by Tufte (1983,p.105) are:

- above all else, show the data
- maximise the data-ink ratio
- erase non data-ink
- erase redundant data-ink
- revise and edit.

The first principle states that the viewer's attention is to be focused on the data's substance. It is not to be distracted by superfluous decoration or the presentation of the graphic itself. The data-ink ratio is the ratio of data-ink to the total ink used to print the graphic. This ratio improves with the removal of non-data ink and/or redundant data-ink. Non-data ink does not reveal information to the viewer. An example of non-data ink is a label for every tick mark on an axis. Redundant ink repeatedly represents the same data. For example, the bar in a bar chart repeats the same information.

Although Tufte concentrates on the production of statistical graphs, the principles used should apply, at the general level, to many other forms of graphics.

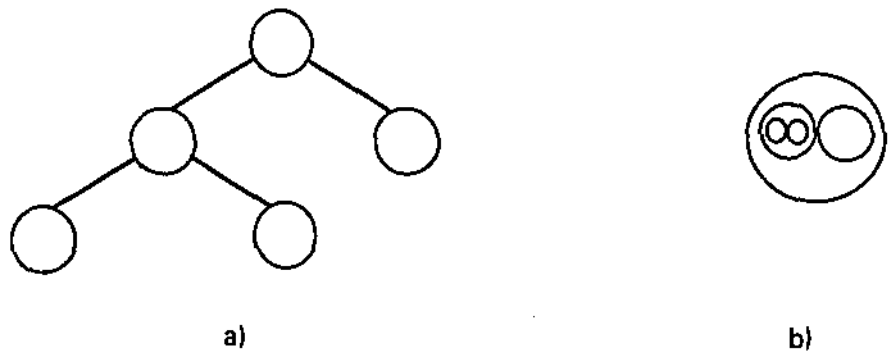
### **2.3.2      Methods used in graphic production**

Tufte (1990, p.46) outlines various methods useful in the production of statistical graphics. They are: layering and separation of data; macro/micro

readings; the use of small multiples (tiling); colour; and narratives of space and time.

Layering and separating of the data identifies the relationships with data creating a hierarchy. This hierarchy can be used to structure the resulting visualisation. For example, Figure 1a is a binary tree clearly showing the layers and relationships within the data. Figure 2, showing the structure of data visualisation techniques, is another visualisation of a hierarchy.

Alternatively, the hierarchy from Figure 1a can be visualised using graphical elements of differing sizes to show the same relationships. The resulting image is called a macro/micro reading. Figure 1b, a macro/micro reading, visualises the same data as depicted in Figure 1a.



*Figure 1.* Two possible visualisations showing the hierarchy and relationships within data.

- a) A binary tree.
- b) Macro/micro reading

The small multiples method is most useful when all the images are within the scope of the eye span. For example, comparison of series of images on the same page reveals more information, more quickly than a comparison of the same images printed on successive pages. Narratives of space and time

represent space and time within the same graphic. This can be achieved by presenting space and time in contiguous slots (or tiles) within the same graphic and on the one page. This type of design is widely used for describing a life cycle or a food chain.

### **2.3.3 Objectives of graphic design**

As data visualisation is a tool to help people understand data at a new or different level, pretty pictures alone are not adequate (Reuter, 1990). All communication between the makers and the readers of the image will take place on a two-dimensional surface (Tufte, 1990). Bearing this in mind, the objectives of a graphic are that it should:

- show the data
- create the image in a way that focuses attention on the data's substance, rather than on the creation or format of the image
- avoid distorting the data
- present many numbers in a small space in order to make large data sets understandable
- encourage comparison between parts of the data
- reveal the data at different levels, from broad overview to fine detail
- serve a purpose, that is, either describe, explore, tabulate or decorate (Tufte, 1990).

These points aid in the retention and clarity of both understanding and communication (Tufte, 1983, p.13).

## **2.4      *Cartography***

As the project's data is geographical in nature, we examine the long established science of cartography. The oldest surviving map (drawn on a clay tablet) is believed to be around 5000 years old (Robinson, Sale & Morrison, 1978, p.15). "Cartography can be succinctly described as the art, science and technology of making maps of the earth or other celestial bodies" (Robinson et al., 1978, p.4). Map production is accomplished by following a series of fundamental steps. Firstly, choose a scale. This is the dimensional reality between the map and the domain it represents. Secondly, choose a map projection. This transforms the spherical nature of the world onto a two-dimensional surface. Thirdly, generalise what is to be mapped. This divides the data into essential and non-essential components, thus reducing what needs to be represented. Fourthly, choose the graphic representations to be used on the map. These should be legible, appropriate to the purpose, and logically related. The last step is the map construction (Robinson et al., 1978, p.5). Clearly these steps closely parallel the design methods and principles discussed in Chapter 2.3.1 and 2.3.2.

## **2.5      *Data visualisation***

### **2.5.1      Introduction.**

The visualisation of data using computer generated images is rapidly becoming more widespread. Much research into the different methods of representing data has been completed. The components common to many methods, which can be used separately or combined in a variety of ways, are: points; lines; curves; surfaces (plane polygon or curved); and colour. For

example, a point or a dot represent the smallest object; surfaces of different sizes represent different sized objects; contours (lines, curves and colour) join observations of equal value; or arrows (lines and colours) and ribbons (surfaces and colours) show flow attributes (Earnshaw & Wiseman, 1992; Firebaugh, 1993).

When envisioning data we can display the AVO using special purpose hardware to create a three-dimensional image, or use more commonly available technology that restricts the visualisation of the three-dimensional (and often multi-banded) data to the two spatial dimensions of the viewing surface. When choosing the latter option, there are two distinct ways to visualise data: *dimension reduction* and *dimension encoding*. Dimension encoding can be divided into *volume visualisation* and *surface visualisation*. Figure 2 displays these visualisation categories.

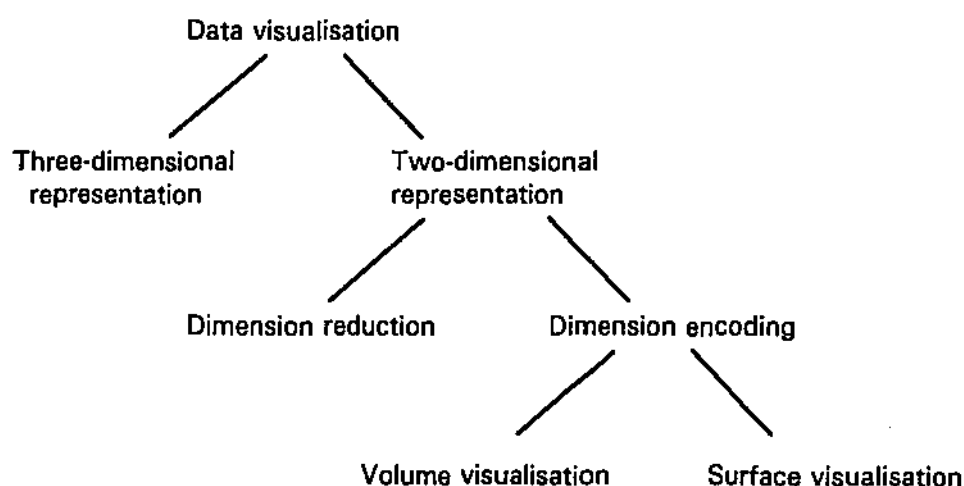


Figure 2. Visualisation categories.



### **2.5.2 Three-dimensional image creation**

The methods to generate a three-dimensional image include: flexible mirrors and stereoscopic views. Three-dimensional views may be obtained by reflecting the screen image off a flexible, vibrating mirror. Stereoscopic views are obtained by simultaneously displaying a pair of two-dimensional images. One of the images is displayed to the left eye, and the other to the right eye (Crawford & Fall, 1990; Foley et al., 1991; Hearn & Baker, 1986). This form of visualisation uses binocular disparity (stereopsis) to give the indication of depth. If the individual images are displayed via glasses, this form of visualisation restricts the number of simultaneous viewers to one.

### **2.5.3 Two-dimensional image representation**

Dimension reduction displays the data as a series of two-dimensional graphics. The number of graphics required equals the number of dimensions. One type of dimension reduction technique is projection pursuit. This interactive technique repeatedly selects directions in data space (different bands) and projects them onto one, two or three display coordinates. The data is either linearly or non-linearly mapped. The use of non-linear mapping can reveal subtle information not revealed in a linear mapping. Using three display coordinates reduces the number of plots to analyse. The direction selection can either be manual or automated. To achieve a good result, successive images must be close to their immediate neighbours (Crawford & Fall, 1990).

This type of visualisation technique is useful for multi-banded data.

However, it is of little use for data of the type used in this project (single-

banded), therefore the project will concentrate on the alternative techniques of dimension encoding.

Encoding the third and higher dimensions will lead to a compromise between clarity (ease of understanding) and completeness of the data representation (Tufte, 1990, p.15). There are two approaches to dimension encoding. The first is *volume visualisation* and the second is *surface visualisation*. Each approach has its strengths and weaknesses. The nature of the data and the type of analysis required usually determines the approach chosen. Depth, the third spatial dimension, is usually encoded into a two-dimensional representation since the viewing surface lends itself to visualising the other two spatial dimensions.

Volume visualisation represents all of the three-dimensional data (not just the surface) with voxels (volume element - a pixel in three dimensions) describing the datum's visual properties (for example, colour, opacity or shading) (Earnshaw & Wiseman, 1992, p.25; Frenkel, 1989; Fuchs, Levoy & Pizer, 1989). A pixel's value is obtained by 'blending together' the voxel values that correspond to that pixel. This method has two advantages: it removes the decision process of what a particular pixel actually represents, and the object does not have to be geometrically modelled. One disadvantage is its computational expense. (Frenkel, 1989; Fuchs, Levoy & Pizer, 1989). A major difference between volume and surface visualisation is that volume visualisation techniques allow for the visualisation of values under the outer 'skin'. The data used in this project is of a surface, so volume visualisation is not suitable.

Surface modelling is used to represent real and artificial surfaces. A real surface is one the eye can see. An artificial surface is created when the surface modelling is applied to a data value to create a surface we can see. For example, if M&H recorded the temperature and salinity of the water wherever they took a depth measurement (creating a multi-banded spatially distributed set of values), then surface modelling could be applied to create an artificial surface visualising the measurements of water temperature or salinity.

This form of modelling is useful for creating a three-dimensional object (within the visualisation package) from data values obtained through empirical measurement or simulations. An advantage of this form of modelling is that the visualisation software only has to retain the values that are visible from any view (volume visualisation requires all values to be accessible). One disadvantage of this form of modelling is that we are unable to 'see' what is behind the surface (the reason for volume visualisation).

Recent advances in medical imaging and visualisation have resulted in new techniques to create a three-dimensional object from a series of two-dimensional images (slices). These techniques rely on edge detection to identify the object's outer surface. Techniques differ in the detection of edges and the formation of the three-dimensional object. An example of this category of technique is the weaving wall algorithm (Baker, 1990). The resulting object is extremely useful in the medical world for planning surgery and radiation treatment (Baker, 1990; Fuchs, Levoy & Pizer, 1989).

Three common surface representations used to represent surfaces, within the visualisation software, are polygon mesh, parametric and quadratic surfaces.

A polygon mesh consists of a series of connected polygons with each line indicating the boundary between two adjacent polygons. This is also known as tessellation. The realism of a curved surface improves by increasing the number of polygons used within the mesh. However, this increase in realism comes at a cost of increased storage space required and decreased speed of display or interaction. Parametric surfaces use parametric polynomial equations to define points of a surface. A quadratic polynomial defines a quadratic surface (Foley et al., 1991).

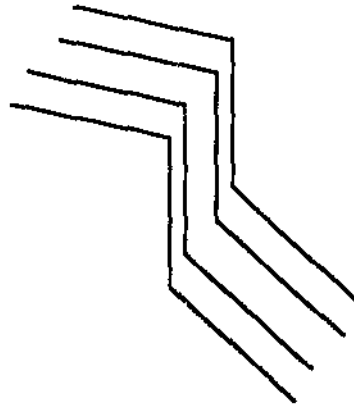
### **2.5.4 Isolines and colour**

The project is directed at representing depth values. Two common ways of encoding depth values are by the use of isolines and colours. Isolines join points with equal values or intensities (Laurini & Thompson, 1992, p.140).

A common form of an isoline is the contour used in cartography. To aid the viewer in determining a value at a particular location, values are written beside every  $n$ th contour, and a scale given to indicate the rate of change between contours. Alternatively, a colour scale can be used to draw the contours. This reduces the amount of information required within the map (and redundant data-ink), but relies on the viewer's ability to differentiate between the colours present in order to choose the appropriate height value from the map's key. The number of contour levels should be chosen carefully to allow the use of pure colours and not rely heavily on people's ability to differentiate between shades (see Chapter 2.8 for a discussion on colour).

A variation of isolines is lines of constant  $x$  (equidistant lines) depicting the outer surface of an object. Changes of depth values are shown by either

changes in the image's  $x$  and  $y$  values, or using colours, or a combination of both. Baker (1990) describes this type of visualisation as epipolar planes. A similar effect is the image obtained from structured light (a sheet of light) being projected onto a object. Figure 3 is an example of lines of constant  $x$ .



*Figure 3* Object's surface depicted by lines of constant  $x$ .

A solid colour map is created when every point to be visualised is displayed with a colour representing one value or a range of values. The use of colour should help the viewer to compare, contrast and track areas distinguished by colour quickly and easily. The considerations associated with the use of colour are explored in Chapter 2.8.

### **2.6**      *Other techniques used in data visualisation*

It is impractical to suggest that a single, static image can reveal all the data in a large data set. Therefore, motion may be employed to increase the amount of information revealed. Rotation of the image within the two-dimensional viewing surface uses motion parallax to indicate depth and reduce the ambiguities of the three-dimensional to two-dimensional projection (Crawford & Fall, 1990; Hibbard, Dyer & Paul, 1992).

Animation is another method that relies on motion to portray depth and movement. As Foley et al. (1991) state " . . . a moving picture is worth ten thousand static ones". Animation can be either a series of images portraying different view points of the same object(s), or can display a sequence of images (time-series) in the same location of the viewing plane.

User interaction is essential in visualisation systems. The nature of this user interaction varies from choosing the data values to visualise, or the form of visualisation, to interaction with the display. Interaction with the display is usually achieved by changing the viewpoint with respect to the image. This is achieved by a variety of camera movements. These include zoom, rotation, translation, pan, and dolly (Foley et al., 1991; Helman & Hesselink, 1989)

## **2.7      *Graphic techniques used to indicate depth***

### **2.7.1.      Introduction**

There are several graphics techniques, as opposed to data visualisation techniques, that provide for the inclusion of depth information in a two-dimensional image. These techniques provide a more 'realistic' image. Some of these are: parallel projection; perspective projection; intensity (depth) cueing; depth clipping; hidden-line removal; hidden-surface removal; shading; and exploded and cutaway views. The technique chosen is dependent on the type of data to be displayed and the form of analysis to be performed on the resulting image (Foley et al., 1991; Hearn & Baker, 1986). These techniques are explained in the following paragraphs.

### 2.7.2 Types of projection

Projection of an object's points along parallel lines onto the viewing plane, such as a computer monitor, is referred to as *parallel projection* (see Figure 4). This type of projection preserves the relative dimensions of the object, but does not give a realistic view because it does not coincide with our every day viewing experiences. Parallel projections are classified by the angle of the projection lines intersecting the viewing plane. An *orthographic projection* is when the angle of projection is perpendicular to the viewing plane. The most common examples are the front elevation, top (plan) elevation and side elevation projections used in technical drawings. As elevation projections only project one face of an object, the three-dimensional nature can be difficult to ascertain, even when two or more faces are displayed simultaneously. An *axonometric orthographic projection* is when more than one face is displayed. *Isometric projection* is the most commonly used form of axonometric orthographic projection. This type of projection has each coordinate axis (in which the object exists) equidistant from the viewing plane (Firebaugh, 1993; Foley et al., 1991; Hearn & Baker, 1986; Mielke, 1991).

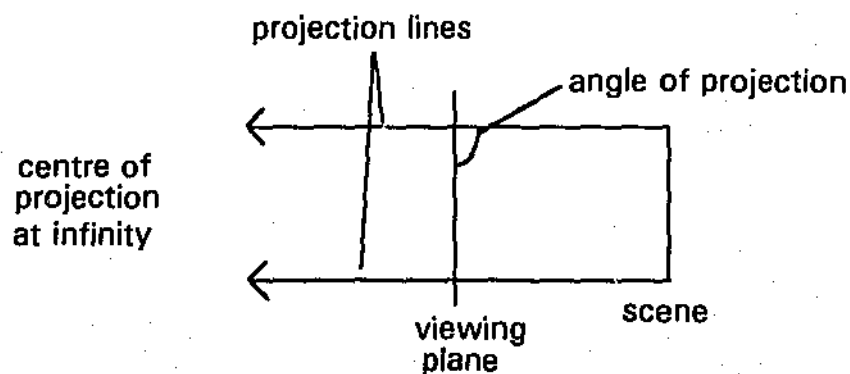


Figure 4. Parallel projection

An *oblique projection* (a form of parallel projection) occurs when the angle of projection is not perpendicular to the viewing plane (Firebaugh, 1993; Foley et al., 1991; Hearn & Baker, 1986; Mielke, 1991). According to Foley et al. (1991) and Mielke (1991), oblique projections combine properties of the front, top and side orthographic projections with those of the axonometric projection. Commonly used oblique projections are the cavalier and cabinet. For the *cavalier projection*, the angle of projection to the viewing plane is  $45^\circ$ . For the *cabinet projection*, the angle of projection to the viewing plane is  $\arctan(2)$ , or  $63.4^\circ$ . This produces a more realistic image as the lines perpendicular to the viewing plane are projected as half their length. This foreshortening is more in keeping with our other (real-world) visual experiences.

*Perspective projection* is projecting points of an object along lines that converge into a point called the centre of projection (see Figure 5). The centre of projection is usually a point in space between the viewing plane and the viewer. This form of projection provides a more realistic image than parallel projections, but distorts the object's relative dimensions (Crawford & Fall, 1990; Firebaugh, 1993; Foley et al., 1991; Hearn & Baker, 1986; Mielke, 1991).

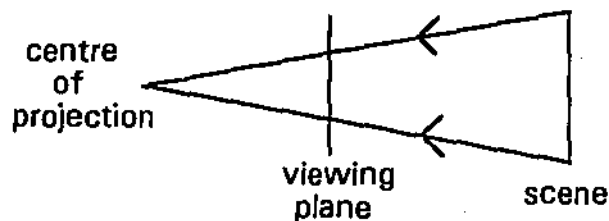


Figure 5. Perspective projection.

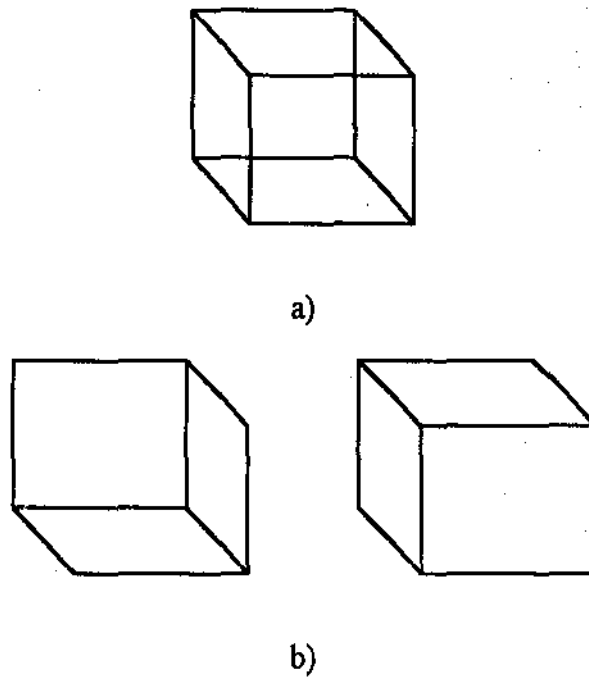


### **2.7.3 Other forms of depth indication**

Intensity cueing indicates depth within an image by varying the intensity within and between objects. This reflects the principle of distant objects appearing dimmer than closer ones (light and shade monocular depth cue) (Firebaugh, 1993; Foley et al., 1991; Hearn & Baker, 1986).

Depth clipping uses a back, and an optional front, clipping plane that the user can manipulate. The back clipping plane removes all parts of the image between the clipping plane and the back of the image. The front clipping plane removes all parts of the image between the viewer and the plane. Additionally, all points on the intersection between the object and the clipping plane(s) can be highlighted to help indicate the clipping plane(s) location (Foley et al., 1991; Mielke, 1991).

Hidden-line and hidden-surface removal are important techniques in the creation of realistic images as they remove lines and surfaces obscured by other objects. These techniques help reduce ambiguities (Firebaugh, 1993; Foley et al., 1991; Hearn & Baker, 1986; Mielke, 1991). For example, people examining a Necker's cube (Figure 6a) can interpret the cube as being in one of two possible orientations. The apparent orientation of the Necker's cube can change during examination, and can leave the viewer wondering which aspect is correct. Figure 6b is the result of applying hidden-line or hidden-surface removal to the image. This removes any confusion as to the orientation of the cube's outer surfaces.



*Figure 6.* Necker's cube.

- a) As wire frame representation.
- b) After hidden-line removal showing the two possible orientations

Shading involves the calculation of light intensity for each given point within a surface. The calculation is dependent on the light source (point or distributed, intensity of radiation, or the colour), the albedo and orientation of the surface and the distance of the object from the light source. Two shading models widely used in computer graphics are Gourand and Phong (Firebaugh, 1993; Foley et al., 1991; Hearn & Baker, 1986; Mielke, 1991). Both are interpolative algorithms, but the distinctive difference is that Gourand interpolates shading while Phong interpolates the normal vector (of the surface). Gourand is the faster algorithm but lacks realism. Phong's algorithm produces more realistic shading but also has greater computational expense (Firebaugh, 1993; Foley et al., 1991).

An exploded view shows the components of an object, including those that are invisible when the object is whole. Cutaway views remove the visible surfaces of an object to reveal the normally hidden surfaces (Foley et al., 1991; Hearn & Baker, 1986).

## **2.8      *Colour***

### **2.8.1      Introduction**

Colour is an important topic that is as large as it is complex. It has many aspects including physical, chemical, physiological, optical, psychological and neurological (Birren, 1988, p.7). These aspects have been examined in detail by a range of professions, varying from art to psychology. An understanding of colour fundamentals is necessary in order to make effective use of colour within the area of data visualisation.

### **2.8.2      Perception of colour**

Colour does not belong to an object or space, but is a visual and neural interpretation of the stimulation of the human visual system (Birren, 1988, p.7). Many factors influence the perception of colour, some of which will now be discussed.

Within the human eye there are three separate receptor systems for the detection of colour. Each has a different spectrum absorption. The wavelengths that provide peak absorption correspond roughly to red, green and blue. Hues are perceived by the comparative response of each receptor system when stimulated by light. Therefore, if any one of these receptor systems is missing or not functioning correctly, the person will have

difficulty in differentiating between colours. The various forms of colour blindness include dichromats (missing one colour receptor system), monochromats (missing two or all three colour receptor systems) and anomalous trichromats (all colour receptor systems are present, but the colour perception is anomalous) (Haber & Hershenson, 1973).

The perceived brightness or intensity of a surface varies with the colour (it is a function of wavelength). Colours in the middle of the spectrum (for example, green) appear brighter than colours at the ends of the spectrum (for example, blue or red) when being radiated with the same energy (Low, 1991, p.13). As gradual changes in brightness are hard for humans to perceive, it is recommended to use abrupt changes of brightness for a scale (Russ, 1992, p.5).

The perceived hue and size of an area change with the surrounding or background colour(s). When the six hues (yellow, orange, red, violet, blue and green) are present on a black background, yellow seems to advance in front with violet in the background and the remaining colours in between. This spatial effect is reversed on a white background (Itten, 1970, p.77). The spatial effect of colour should be used when encoding depth into an image. For example, on a black background yellow should be used for values closer to the viewer and violet for values further away from the viewer.

### **2.8.3      Suggestions on the use of colour**

Several colour scales are used within visualisation software systems to encode the third and higher dimensions. They include:

- achromatic (grey-scale)
- spectral-order sequences in either decreasing or increasing order
- spectral-order sequences with extra colours inserted
- scales that vary in saturation or lightness (hue is constant)
- scales that cycle through the hues with increasing lightness and/or saturation
- scales with physically-inspired colour ordering
- scales with arbitrary colour ordering (Robertson, 1992).

According to Meyer (1991), when choosing a colour scale to encode information, perceptually uniform "colour spaces" is accepted as the best to use. The colour scale used should be displayed next to the image. When displaying the colour scale as a series of colour samples, the following considerations should be observed:

- size of colour sample should be constant
- spacing between colour samples should be constant
- the luminance and chromacity of the background should be constant
- the luminance and chromacity of any ambient light (reflected light within the image) should also be constant.

Unfortunately, this uniformity is not maintainable within the interior of an object due to the effects of colour contrast. Rendering of a three-dimensional object is done either with shading or changing the luminance of the colour.

### **2.8.4 Conclusion**

The use of colour within a visual representation is a contentious issue.

Applied appropriately, the use of colour is a powerful technique for encoding

information. If colour is not used appropriately, the resulting image can convey either misleading or little information which are results far removed from the objective of data visualisation. An artist knows how to use colour to visual advantage and a perceptual psychologist understands the effect of colour has on people. When choosing a colour scale, the creator of an image should try to combine the knowledge of both these specialists to improve the quality of the work.

## **2.9**      *Choice of visualisation or graphic technique*

### **2.9.1**      **Interpretation of graphics**

Graphical images are interpreted differently by different people. The creator of a visual image must take into account the possible variations in human vision and perception that may occur when looking at, and analysing, the image. As has already been observed, the human visual perception system is complicated and, although all individuals possess similar systems, there will be variations on how different individuals perceive an image (Tukey, 1990). Creation of the image must therefore take into account the irregularities that may occur, such as the various forms of colour blindness.

### **2.9.2**      **Limitations of techniques**

"No single representational technique can hope to provide insight into all types of analysis data" (Schroeder, Volpe & Lorenson, 1991). Generally, in comparison to the amount of work done in the creation of a given graphical representation, very little thought is given to what form of graphical representation would be best suited to the type of data to be displayed. The choice of the graphical representation is often left to the discretion of the

person creating the image. This approach is highly subjective and relies heavily on the experience, and the personal preferences, of the creator.

### **2.9.3 Call for standards**

Robertson (1990) suggests that identification of the representations and classification of the different visualisation techniques are important steps to overcome the problem of subjectivity. The identification process should take into consideration:

- how people organise and process visual knowledge
- the identification of problem areas and anomalies in the field of visualisation
- how to convey knowledge visually.

This classification will enable the creator to make an informed decision on which type of representation to use.

Tukey (1990) suggests a few more principles to take into account when choosing a representation:

- careful choice, and expression, of scales is essential
- objects are perceived in relation to their surroundings
- straight lines are easier to perceive than curves
- horizontal lines are easier to perceive than oblique lines
- things that are closer together are easier to compare than things far apart
- things of equal importance should have roughly equal visual impact
- irrelevant material can seriously interfere with a plot
- motion is more effective for conveying three-dimensional depth than stereopsis or perspective

- principles of good graphical display are often in conflict with each other, necessitating trade-offs amongst them.

### **2.10      *Interpolation techniques***

Interpolation derives new values based on existing values. By interpolating between the established surveys, a process known as "tweening" in the animation world, it is possible to generate smooth sequences that make it easier to understand the changes occurring in the underlying data. The interpolation process can either derive new values for each point (based on its start and end value) or derive new locations for an object (based on its start and end locations). The function used to derive the values can be of any form.

Morphing is an interpolation method for deriving locations of objects within the image between start and end locations. Morphing, short for metamorphosis, is a method used extensively in the entertainment industry that transforms one image or object into another.

According to Sørensen (1992), the word takes on two different meanings in computer graphics. This is due to the difference in techniques because of the availability of raster and vector-based graphics. For raster-based graphics, morphing is a two-dimensional process that stretches and deforms parts of an image in a frame buffer. A morphing algorithm for raster-based graphics relies on the user to determine the key points in both images, and specify the relationships between the key points.

Morphing in vector-based graphics refers to the process of transforming a three-dimensional object into another by translating polygonal vertices in



digital space. In vector-based graphics, objects are defined with key points. The morphing process uses these key points to control the transformation. The user does have the option of specifying which key points in the original object correspond to key points on the resulting object, or alternatively may allow the algorithm to determine the correspondence (Sørensen, 1992).

### **2.11     *Motion analysis***

This project is interested in forms of motion analysis new to M&H. We need to be able to identify and indicate changes between surveys. This project is using an *optical flow* algorithm developed for computer vision to indicate direction and magnitude of changes in the floor of the harbour.

Optical flow, according to Horn & Schunck (1980) is "apparent velocities of movement". It is "apparent velocities" because the optical flow of a moving image does not necessarily indicate the motion of the underlying objects. For example, a candy-striped barber's pole rotates around its  $y$  axis, while the optical flow velocities indicate the movement is along the  $y$  axis. The optical flow of an image pair is a system with two degrees of freedom at each pixel (the horizontal and vertical components of the flow). To solve these we need two constraint equations for each pixel. How these constraints are obtained divides the optical flow algorithms into two broad categories: *token-based* and *derivative-based* methods.

Token-based methods use image features that give two constraints. Features (tokens) need to be identified and tracked. This effectively removes the second constraint problem but introduces the correspondence problem (identifying the token across the images) (Cooper, 1992). The nature of the

project's data does not lend itself to identification of tokens, therefore token-based methods are not investigated further.

An example of a derivative-based method was presented by Horn and Schunck (1980). The algorithm derives the optical flow, for each point (dense optical flow), between a sequence of images obtained by cameras. Their first constraint, the *derivative constraint*, was based on the assumption that the motion of the brightness values corresponds directly to the motion of the surface. For this to be true, more assumptions were made in order to link the image of the object to the actual object. These assumptions included: the surface within the image was flat; incident light was uniform across the image; reflectance across the surface varied smoothly with no spatial discontinuities; and there was no occlusion of objects (Horn & Schunck, 1980).

The second constraint was obtained from the *smoothness assumption*: neighbouring points move at similar rates in similar directions (Horn & Schunck, 1980).

Ballard & Brown (1982, p.105) give the algorithm as

$$k = 0$$

Initialise all  $u^k$  and  $v^k$  to zero

Until some error measure is satisfied, evaluate

$$u^k = u^{k-1} - f_x \frac{P}{D} \quad (\text{Equation 1})$$

$$v^k = v^{k-1} - f_y \frac{P}{D}, \quad (\text{Equation 2})$$

where

$$P = f_x u_{av}^{k-1} + f_y v_{av}^{k-1} + f_t \quad (\text{Equation 3})$$

$$D = \lambda^2 + f_x^2 + f_y^2, \quad (\text{Equation 4})$$

In the algorithm above,  $u^k$  and  $v^k$  are the optical flow velocities in the  $x$  and  $y$  direction,  $u_{av}^{k-1}$  and  $v_{av}^{k-1}$  are the average of a point's and its surrounding neighbours'  $u$  and  $v$  values from the previous iteration.  $f_x, f_y$  and  $f_t$  are the partial derivatives of brightness with respect to  $x, y$  and  $t$  (time).

$\lambda$  is a supplied value. However, the smaller  $\lambda$  is, the closer the derived value is to the true value. A large  $\lambda$  increases the value of  $D$  which leads to a

decrease in the result from  $f_x \frac{P}{D}$  and  $f_y \frac{P}{D}$ . This lowers the effect the partial derivatives of brightness with respect to  $x$  or  $y$  has on the calculated optical flow value.

The most common way of visualising the optical flow velocities is by needle diagrams. The needle, a modified form of arrow, indicates the direction and magnitude of the optical flow. Instead of having an arrow head to indicate direction of flow, the needle indicates its origin.

## **Chapter 3. Method of investigation**

### **3.1 *Resource description***

#### **3.1.1 Data**

The data provided for the project (courtesy of M&H) corresponds to a 100 by 100 metre grid map, with depth values representing the grid's intersection points. The interpolation process that generates the grid uses the special value, 999.9 to indicate a missing value. The data was formatted as a series of triples (northing, easting, depth).

#### **3.1.2 Hardware and software**

The motion analysis and interpolation experimentation were conducted on a micro computer running LINUX, a UNIX clone. Image Processing Recognition System<sup>1</sup> (IPRS), was used for the actual experimentation. IPRS contains data structures, a library of input and output routines, and a suite of programs to facilitate convenient manipulation and display of the depth data.

### **3.2 *Current visualisation techniques***

At the date of project commencement, the main form of visualisations M&H relied on were in-house developed software to extract values and MicroStation, a CAD package, to display them. The main form of motion analysis was the examination of difference maps. Since that time, M&H have

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<sup>1</sup>developed by Department of Computer Science at The University of Melbourne,

purchased SiteWorks<sup>2</sup>, a proprietary data visualisation package, to expand their data visualisation capabilities. SiteWorks creates a spatial model to represent the surface as series of triangles forming a tessellation or mesh (AVO). Techniques for visualisation include: contours, solid colour maps, profiles (lines of constant  $x$ ), and vectors (coordinates, slope direction and degree for each triangle's centre). Colour encodes the slope, elevation or aspect of each tessellation triangle. A limitation of the software is that it does not provide a method for data interpolation for periods in between the surveys, or for motion analysis.

MicroStation provides animation on screen and allows for the transfer of images to video tape. User interaction allows the viewer to change the viewpoint in a variety of ways (for example, zoom in or out).

### 3.3 *Motion analysis algorithm*

Horn & Schunck's (1980) algorithm was implemented to perform this project's motion analysis experimentation. The assumptions made for the first constraint include: the surface within the image was flat; incident light was uniform across the image; reflectance varied smoothly with no spatial discontinuities; and there was no occlusion of objects.

These assumptions were made to link the movement of brightness patterns, which represent an object, to the actual movement of the object. Data used in this project represent the object directly, as it was obtained by empirical

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<sup>2</sup> copyright Integrgraph

sampling and interpolation. Therefore, this project has no concerns with reflection or consistent illumination. Although the surface is not flat, the difference in a point's value between surveys indicates change and is not due to shadowing. As the data represents only one object there can be no occlusion.

Movement of the harbour floor will violate the smoothness assumption, second constraint, in several situations. These include: protrusion of bedrock above the alluvial sediment; collapse of a bank (because of undercutting), or on a channel's curve with erosion on one side and deposition on the other.

$u_{av}^{k-1}$  and  $v_{av}^{k-1}$  (from equations 1 and 2) calculation has two side effects on the derived optical flow values. The first is that the derived values for points in the centre of the image are more indicative than those derived for points on the edge of the image. The second is that the averaging calculation propagates optical flow information across the image. Therefore, the choice of the number of iterations ( $k$ ) involves a trade-off between increasing accuracy of derived optical flow information for parts of the scene where there is flow and decreasing accuracy (spurious flow) of the derived optical flow information for parts of the scene where there is no flow information.

### 3.4 *Experimentation conducted*

The project's experimentation concentrated on techniques useful for interpolation for the time periods in between the surveys, to achieve a longer and smoother animation, and analysis of motion, apart from animation.'

#### **3.4.1. Preprocessing**

Before commencing interpolation and motion analysis experimentation, the depth data was transferred from the original format (a triple per point) into IPRS file (image). Using the IPRS program xshow, these files could be directly visualised, but a set of programs were written to transfer the floating point depth values to a byte brightness value. The missing value, 999.9, was converted to 0 and displayed as black. Valid depth values were transferred to values above 0. The scale was based on the 'deeper is darker' principle with points above the water being converted to 255 and displayed as white. Each grid intersection point was represented by a pixel in the image (see Appendix A).

These brightness images were examined, via a short animation, to determine an area that exhibited movement. To confirm the areas of greatest change, a new set of values were created. This was achieved by subtracting the value for each point in the first year from the corresponding values in subsequent years, a process used by M&H for their difference maps. The resulting sets of values were translated into brightness images (see Appendix B). The advantage of this set of images was that the smaller range of values led to a corresponding increase in the steps of the brightness values.

The identified area was "clipped" out to create a new set of images on which the experimentation was performed (see Appendix C). The first step of the experimentation was to reduce noise. Noise is random fluctuations in the measured value from the true value. Noise reduction was achieved by convolving a low pass filter with the data. This was done to obtain a set of

values more indicative of the true values. The smoothed data was then used for calculating optical flow.

### 3.4.2. Interpolation to create new images

Motion analysis of the harbour floor by M&H is achieved by either comparing static difference maps between each survey's data or animation of solid colour maps. To achieve an understanding of the movement's magnitude and direction requires repeated examination of the maps or the animation.

Animation of the images generated from M&H depth surveys alone is unsatisfactory. Given one image per survey, with differences in the depth value of the points each time, a short, jerky action is unavoidable. Motion analysis based on visual tracking is difficult due to the sudden movement of features.

The aim of interpolating depth values is to create a longer and smoother animation. To create a new set of images, the weighted averages of values from two images were used to generate  $n$  new images. The interpolation process only took place if the grid intersection point had valid values in both 'key-frame' surveys.

The algorithm used for the interpolation experimentation follows:

for  $k = 1$  to  $n$  evaluate

$$f(x, y, t_k) = f(x, y, t_0) + ((f(x, y, t_1) - f(x, y, t_0)) / (n + 1)) * k$$

(Equation 5)



In equation 5,  $n$  is the number of new values to be interpolated, and  $k$  is the iteration number from 1 to  $n$ .

### **3.4.3. Motion analysis via optical flow**

Optical flow was identified as a viable means for motion analysis of the data. Horn & Schunck's optical flow algorithm was adapted in several ways. The first adaptation was to cater for the value used to indicate missing data: 999.9. This was achieved by creating a 'master' binary image to indicate where the derivative values could be calculated. The algorithm performed the optical flow calculation for these points only. The number of iterations was controlled by either the sum of the rate of change for every  $u$  and  $v$  value calculated being less than a predetermined value, or a count value. Both these values can be determined by the user.

The partial derivatives of brightness with respect to  $x$  and  $y$  ( $f_x$  and  $f_y$ ) were obtained by convolving a Sobel operator with the data. A Sobel operator, a 3 by 3 mask, is used to compute the gradient, the rate of change, for a central point (see Figure 7 ). It has two advantages over smaller masks. The first is due to the larger area making the derivative operation less sensitive to noise. The second advantage is due to the weighting of pixels closest to the central point by a factor of 2. This has the effect of smoothing the data (Gonzalez & Wintz, 1987,p.339).

The derivative with respect to time ( $f_t$ ) was calculated as the difference between a point's value in Image one to its value in Image two. The derivative calculation only took place when all of the image's values to be used in the calculation were valid (that is, not 999.9).

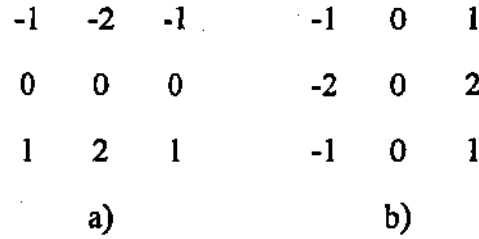


Figure 7. The Sobel operators.

- a) calculates the gradient with respect to  $x$ .
- b) calculates the gradient with respect to  $y$

$u^0$  and  $v^0$ , two arrays the same size as the images, were initialised to 999.9. The average calculation for  $u$  and  $v$  relied on the 999.9 value to indicate that there were no optical flow values for that point. This ensured that the averaging calculation only involved points with optical flow velocities derived.

The resulting optical flow  $(u,v)$  values were then visualised by drawing a line segment (needle) starting at a particular pixel (marked with a cross) and extending in the same direction as the optical flow at that point. For this project, the needle diagram was superimposed over the original image to help in identification of feature movement.

## Chapter 4. Results

### 4.1 Results of experimentation

#### 4.1.1. Interpolation

The resulting images of the interpolated depth values, using weighted averages, when inserted between the original images, did lengthen and smooth the animation. However, this form of interpolation of depth values depicts the feature being eroded from its original position and deposited simultaneously at its destination (see Figure 8b). This movement is contrary to the actual movement of the feature (see Figure 8c).

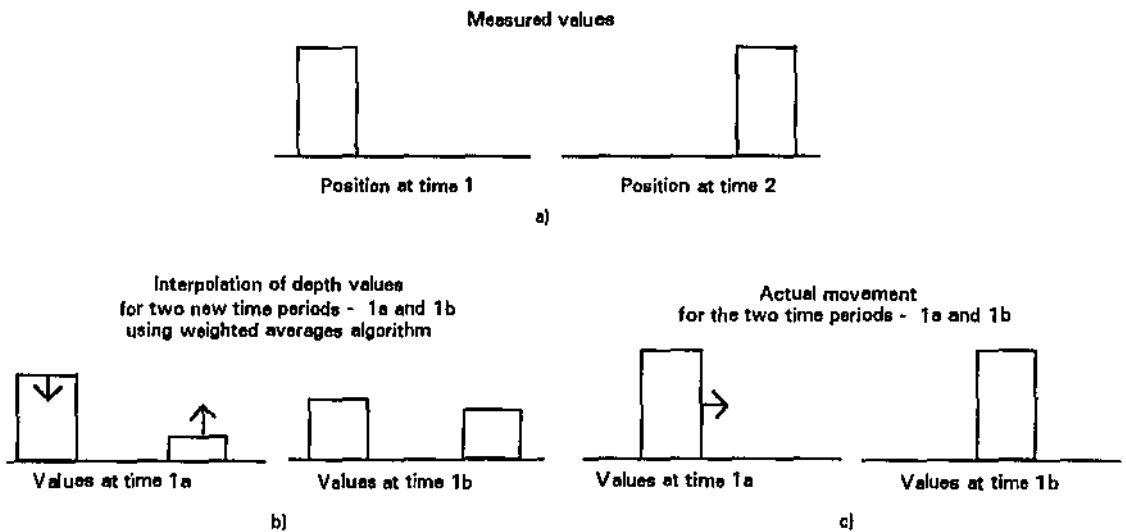
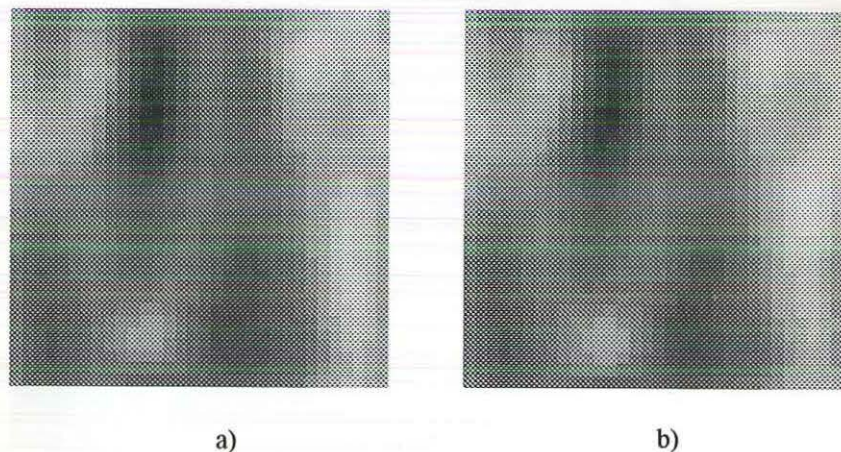


Figure 8. Visualisation of a feature.

- a) The measured values from two surveys.
- b) Two interpolated values for the period between Surveys 1 and 2. Note the movement in the vertical direction.
- c) Expected values for the period in between Surveys 1 and 2. Note the movement is in the horizontal direction.

### 4.1.2. Motion analysis

Movement of features can be discerned by repeatedly comparing brightness images of the data (see Figure 9). There are two ways to improve the comparison process when viewing the images on paper. The first method is small multiples (as in Figure 9). The second method is to print the images, in the same position, with the same size, on successive pages. Appendix A is a series of images depicting the whole of the project's data as brightness images. They have been printed on successive pages so the viewer can, by riffling, effect a crude form of animation.



*Figure 9.* Two depth images, with darker indicating deeper.

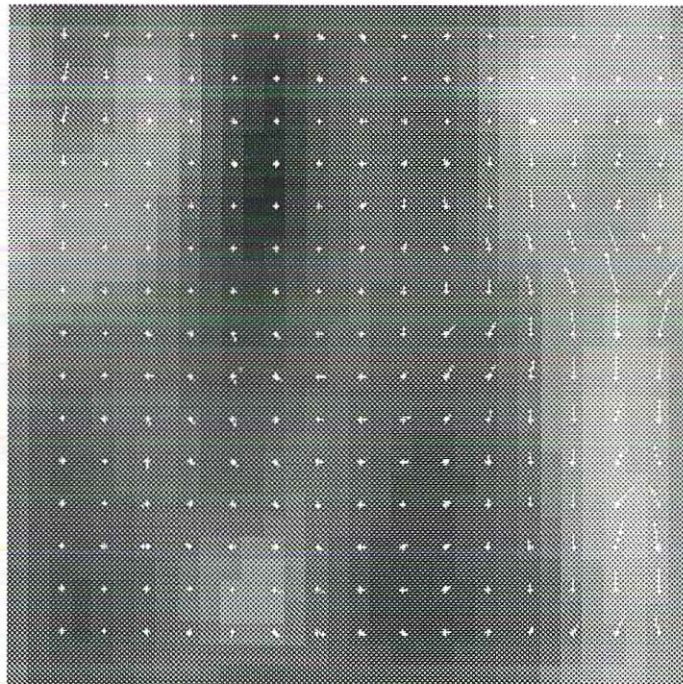
- a) The brightness image for Survey 1.
- b) The brightness image for Survey 2.

To fully appreciate the movement of brightness values between the images, the viewer is required to make many comparisons. Calculation and display of the optical flow are a faster, more reliable (less qualitative) means of motion analysis. The resulting needle diagram clearly displays the movement. Examination of Figure 10 shows the different direction and magnitude of the optical flow for each point in the image. This figure represents the change



between two consecutive surveys. More information can be revealed by examining a series of optical flow needle diagrams depicting motion between a series of surveys (see Appendix D).

Before trying to interpret a needle diagram, the viewer must be sure that the input data sets were a valid pairing. For example, the optical flow figures depicting motion between measured values directly before and after completion of the dredging operation are meaningless.



*Figure 10.* Needle diagram of optical flow between Survey 1 and Survey 2.  
The needles (white) are superimposed over the brightness image of Survey 1.

## **Chapter 5. Conclusions and future directions**

### **5.1 *Summary of literature review***

Expansion of data visualisation using computers is due to two major factors. Firstly, the decreasing cost and the increasing capabilities of hardware make computers more widely available and more attractive to use. Secondly, computers are used for storing large amounts of data. This data is either created directly on the computer, via research and experimentation, or collected by remote sensing. Data visualisation software systems have been developed for the different computing platforms, such as super-, mini-, and micro-computer, and are either freeware, shareware, or proprietary.

For data visualisation to effectively communicate data, we should take advantage of the human visual system, our everyday visual experiences, and our predisposition towards a form of visualisation. For example, stereopsis takes advantage of the human visual system. Encoding our everyday visual experiences can be achieved by, for example, the use of depth cues and different projections of the data onto the viewing surface. A viewer's predisposition toward the visual representation of the data will affect the information obtained from the presented image. This predisposition can work both for and against information communication. For example, arrows are accepted to visualise flow but not to visualise multi-banded data.

Colour can be utilised within a visual representation to encode a dimension or a band from multi-banded data. Difficulty arises when the creator of the

image has not taken into account factors, such as colour blindness and preconception in the meaning of colour. An example of the latter is that to a physicist red and blue stand for low and high temperatures respectively, whilst to a layperson these colours mean exactly the opposite.

Data visualisation, although a powerful tool, still requires the creator of the image to follow a methodology to ensure a well designed, meaningful image. Some of the steps involved in creating an image are: the identification of the data type; the identification of the purpose of the image; and the choice of the technique(s) best suited to the data and the intended purpose of the image. Associated with the image should be information to aid the viewer to correctly interpret the information. For example, a description of the data source, any data manipulations performed, the values visualised, the colour or brightness scales and the meaning of any special purpose graphical elements must be provided.

## **5.2      *Conclusions drawn from experimentation***

### **5.2.1      Interpolation**

As indicated in Chapter 4.1, interpolation and the subsequent visualisation of these values accomplished the objective of creating a longer and smoother animation. However, it was recognised that the interpolation created false movement within the animation. Therefore, this form of interpolation is of little value in creating an animation to aid in the analysis of motion of the harbour floor.

### **5.2.2 Motion analysis**

The results of the optical flow experimentation indicate that optical flow appears to be a viable alternative to the current forms of motion analysis performed by M&H. The resulting needle diagrams which visualise the optical flow velocities can be viewed in several ways. A single static diagram indicates the movement of the harbour floor between two surveys. A series of needle diagrams, depicting the optical flows calculated over a series of surveys, will reveal more information than the single static diagram. Examination of a series of needle diagrams reveals changes in magnitude and direction of movement over time, and this should lead to a better understanding of the ever changing harbour floor.

Horn & Schunk's (1980) optical flow algorithm was applicable for this project. Horn & Schunk (1980) used various assumptions to link changes in the captured images of an object to the actual movement of the object itself. These assumptions, although not applicable for this project, make the algorithm well suited for initial experimentation, as the data is of the object rather than a captured image of the object.

### **5.3 *Future directions for project's experimentation***

Although the results were indicative of the usefulness of optical flow as a motion analysis, it must be stated that further research and experimentation should be conducted. These should include: improvement of the algorithm, improvement of the data, improvement in efficiency of the experimentation programs; other uses for the optical flow values; and implementation concerns. These points will now be discussed.



### **5.3.1 Improvements to optical flow algorithm**

The results from the optical flow analysis should not be treated as infallible. To improve the quality of the figures produced, the constraints of the algorithm should be changed to reflect the actual alluvial movement.

### **5.3.2 Improvements in data (sampling)**

The data used for optical flow calculation were the intersection points of a 100 by 100 metre grid. It is possible, with the current sampling, that one point represents a fast flowing (therefore eroding) channel, whilst one of its neighbours represents a stationary sand bar, and another indicates where deposition occurs. Thus the smoothness constraint is causing the derivation of false values because it propagates the optical flow velocities across the data. A decrease in the sampling distance should lead to a corresponding increase in the quality of the derived values, making them closer to the actual movement.

### **5.3.3 Improvement of experimentation programs**

The experimentation programs can be extended in several ways to improve their usefulness. For example, the optical flow could be calculated between a series of depth surveys, instead of the specified two. If movement is smooth between points, it can be extrapolated that it is smooth(ish) between surveys. Thus, once the optical flow values between Surveys one and two have been calculated, they can be used to replace 999.9 as the starting values for the optical flow calculations between Surveys two and three. This could result in fewer iterations being required for optical flow calculation in ensuing surveys.

Optical flow velocities should only be calculated for points that have a change in depth over time. As animation of a series of images helps reveal information, an animation of the needle diagrams should reveal more information than a series of static ones.

#### 5.3.4 Proposed experimentation

It has been identified that the optical flow values and an interpolation technique, such as weighted averages, can be used to create a series of interpolated images. This is possible because the algorithm calculates optical flow for every point (dense optical flow).

The resulting interpolation, known as morphing, should reflect the actual movement more accurately than the interpolation performed as part of this project.

The proposed algorithm is as follows:

for  $k = 1$  to  $n$  evaluate

$$f_f(x, y, t_k) = f(x, y, t_0) + (u(x, y, t_0) / (n+1)) * k \quad (\text{Equation 6})$$

$$f_f(x, y, t_k) = f(x, y, t_0) + (v(x, y, t_0) / (n+1)) * k$$

$$f_r(x, y, t_k) = f(x, y, t_1) - (u(x, y, t_1) / Q) \quad (\text{Equation 7})$$

$$f_r(x, y, t_k) = f(x, y, t_1) - (v(x, y, t_1) / Q),$$

where

$$Q = (n+1) * (n+1 - k) \quad (\text{Equation 8})$$

In equation 6,  $f_r$  represents the  $u$  and  $v$  values being applied to the first survey to interpolate figures in between Survey one and Survey two. In equation 7,  $f_r$  represents the  $u$  and  $v$  values being applied to the second survey to interpolate figures in between Survey two and Survey one.

In equations 6 and 8,  $n$  is the number of new values to be interpolated, and  $k$  is the iteration number from 1 to  $n$ .

This algorithm will generate two sets of figures which have the format: northing, easting and depth, within the same file. These figures would then be interpolated back to the grid format with a new series of images being created.

If the morphing were successful more experimentation could be conducted to test further the usefulness of the optical flow values. For example, a series of optical flow values could be used to predict future optical flow values. The predicted optical flow could then be applied to the existing depth values, as established in the latest survey, to predict the future shape of the harbour floor. The resultant predictions could make possible an increase in time between surveys and/or delay dredging operations. Either of these possibilities would lead to the saving of resources.

### 5.3.5 Implementation concerns

Several steps must be completed before M&H can utilise the motion analysis programs. These include: the conversion of software to run under the MS DOS operating system; the output data being presented in a format acceptable to MicroStation (the CAD package used for display purpose); and the introduction of a flag to enable the identification of the first survey done

after dredging has taken place. This last step is to forestall the calculation of meaningless optical flow values.

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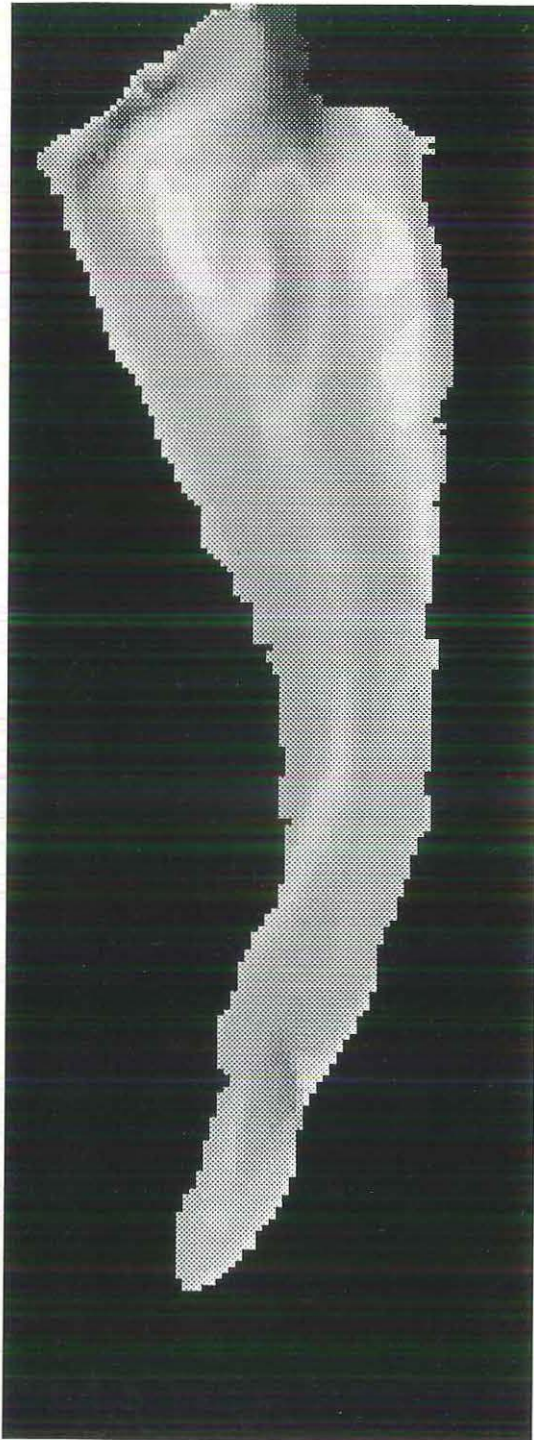
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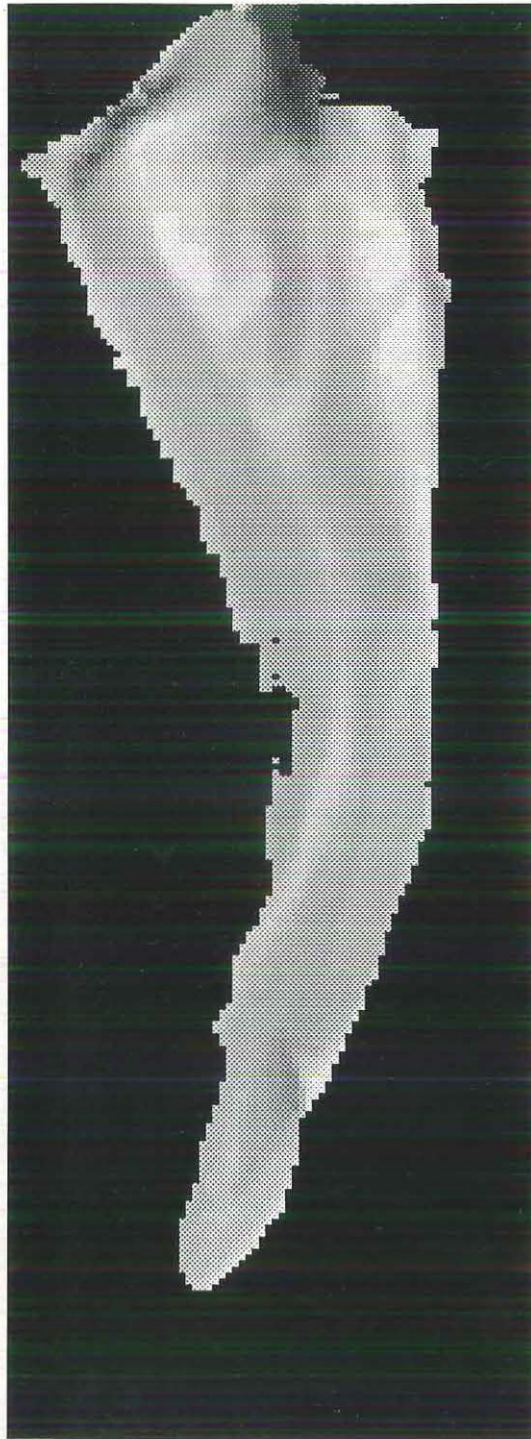
## **Appendix A.**

This appendix shows a series of brightness images displaying the depth data of Cambridge Gulf (Wyndham) over a period of seven years (see Figure 11). Each image was created by assigning brightness values to represent depth values within the data, with darker pixels representing deeper parts in the data. Some depth values in the data are positive, representing parts of the harbour that are above the nominal sea level, and these are presented as white pixels. Black indicates missing values. The direction of water flow is from the bottom to the top of the image.

To help the viewer gain an understanding of the changes over time, the images have been printed with the same position and size on consecutive pages. To gain an understanding of the motion, riffle the images within Figure 11.

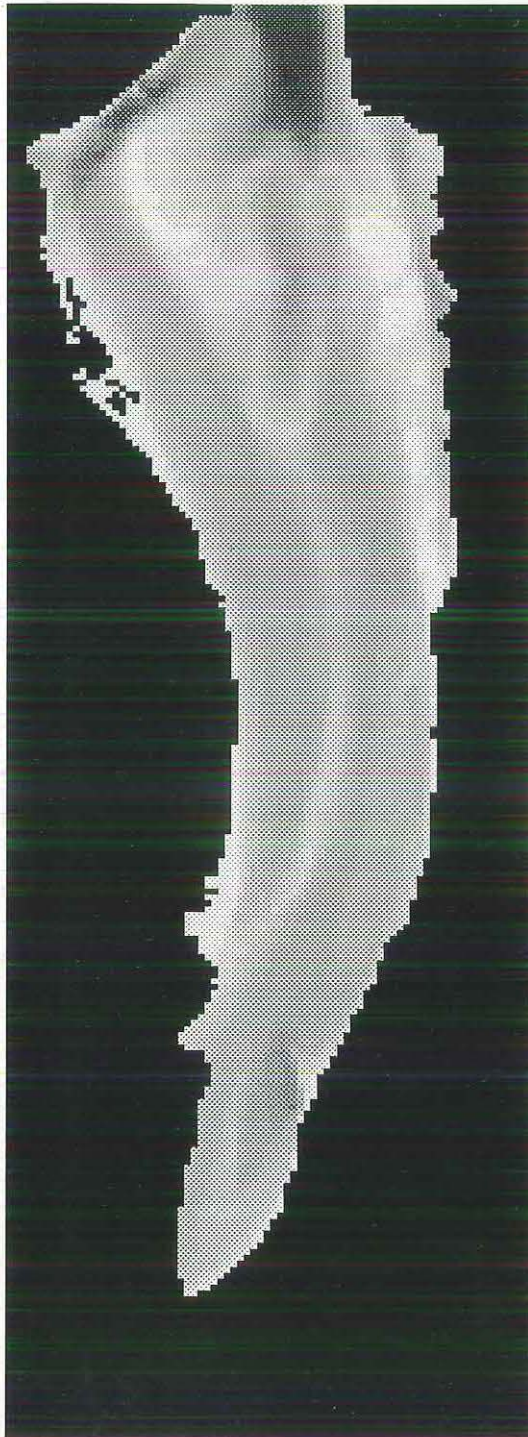


a) Brightness image representing the 1986 depth values of Cambridge Gulf (Wyndham) harbour.

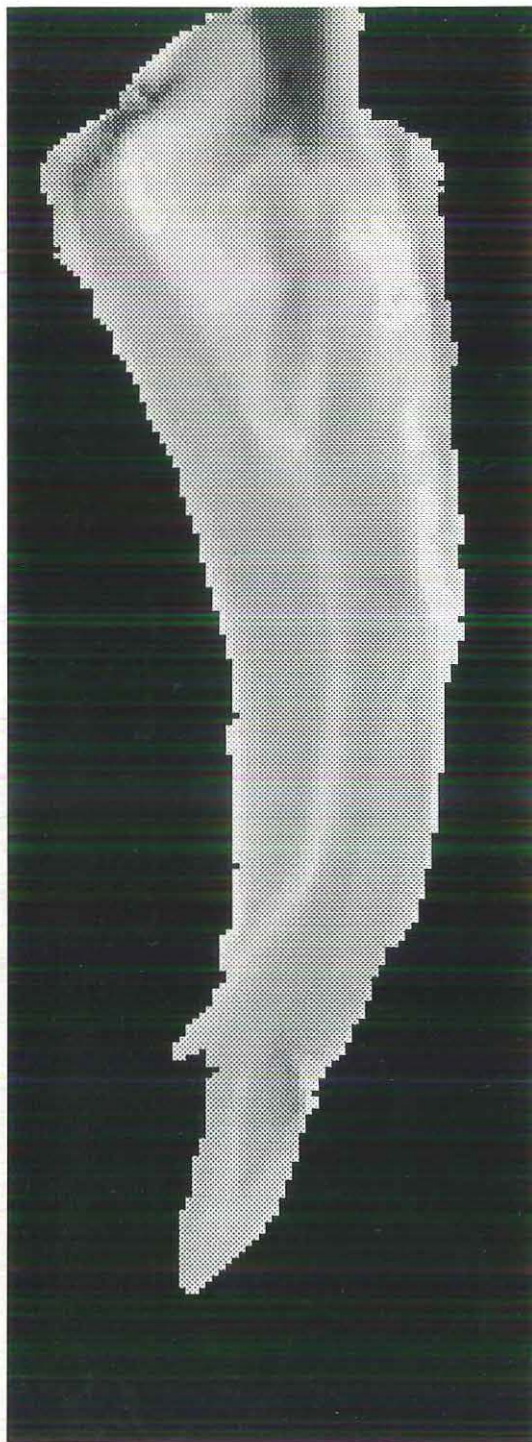


b) Brightness image representing the 1987 depth values of Cambridge Gulf (Wyndham) harbour.



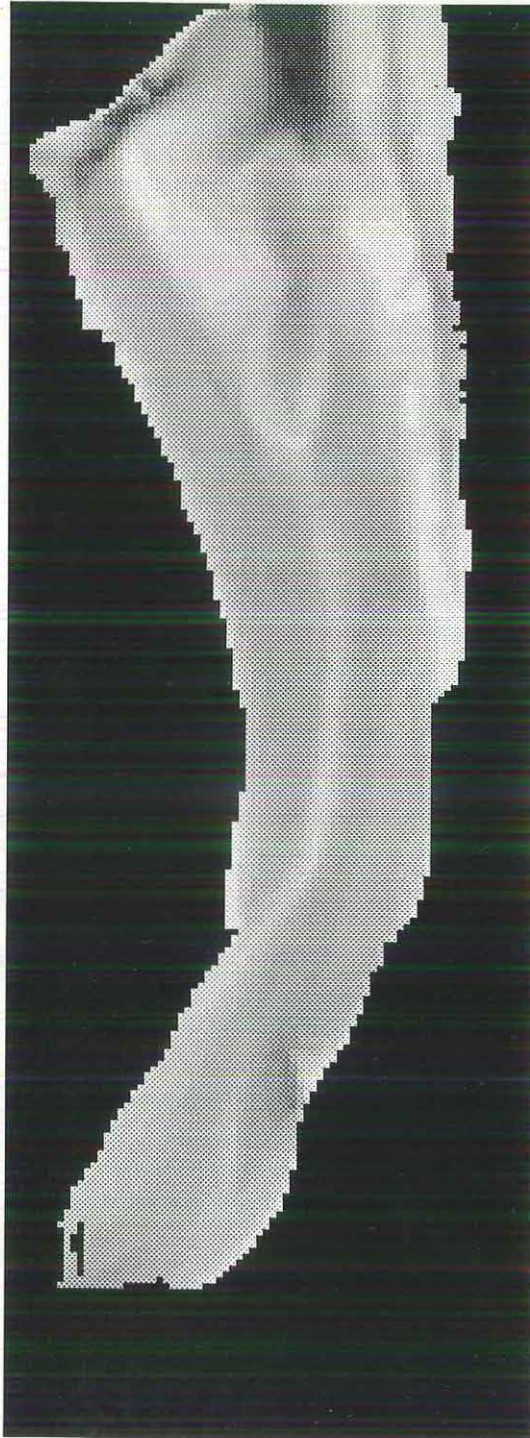


e) Brightness image representing the 1990 depth values of Cambridge Gulf (Wyndham) harbour.



f) Brightness image representing the 1991 depth values of Cambridge Gulf (Wyndham) harbour.





g) Brightness image representing the 1992 depth values of Cambridge Gulf (Wyndham) harbour.

*Figure 11a)..g):* Brightness images representing the 1986 to 1992 depth values of Cambridge Gulf (Wyndham) harbour.

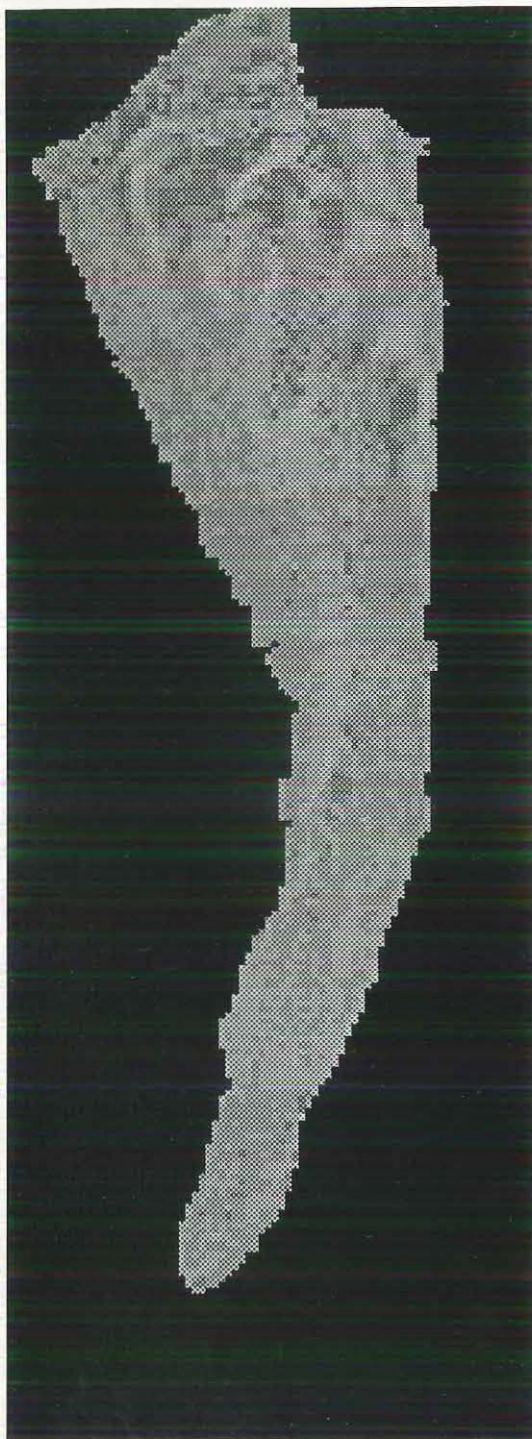
## Appendix B.

This appendix shows a series of brightness images displaying the changes in the depth data of Cambridge Gulf (Wyndham) over a period of six years (see Figure 12). The set of difference values were created by subtracting the depth value of a point in the first survey (1986) from the corresponding point's depth values in subsequent years. The difference value was calculated only if the point had valid values. The direction of water flow is from the bottom to the top of the image.

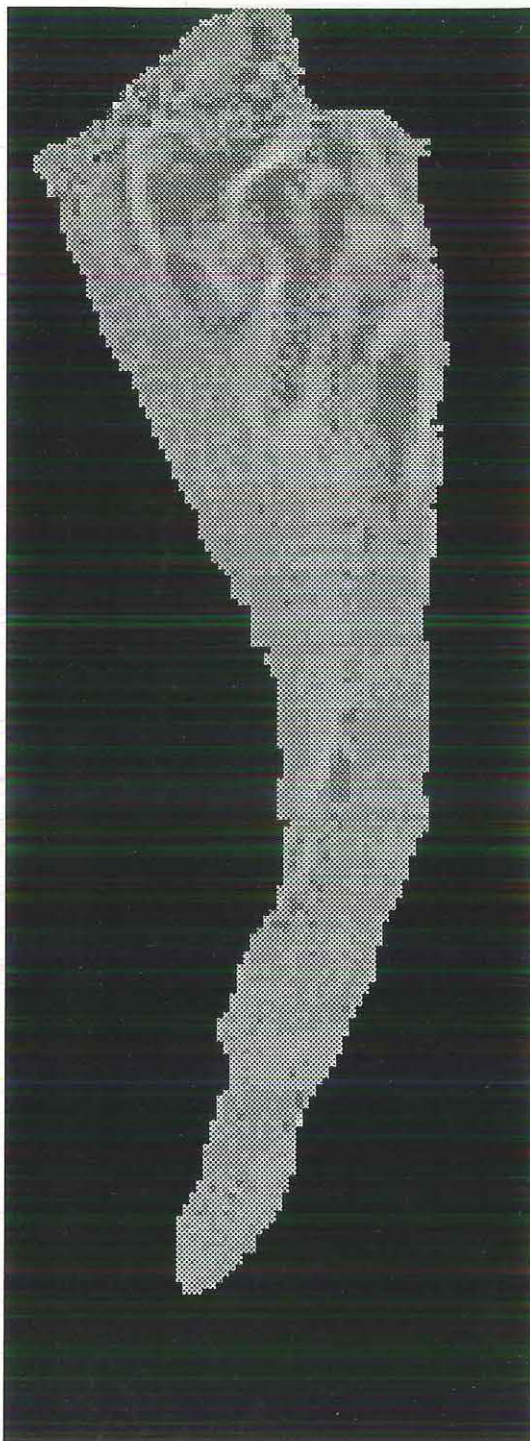
These difference values were transformed into a image by assigning brightness values to represent depth values within the data, with darker pixels representing deeper parts in the data. Black indicates the missing data value 999.9.

To help the viewer gain an understanding of the changes over time, the images have been printed with the same position and size on consecutive pages. To gain an understanding of the motion, riffle the images within Figure 12.



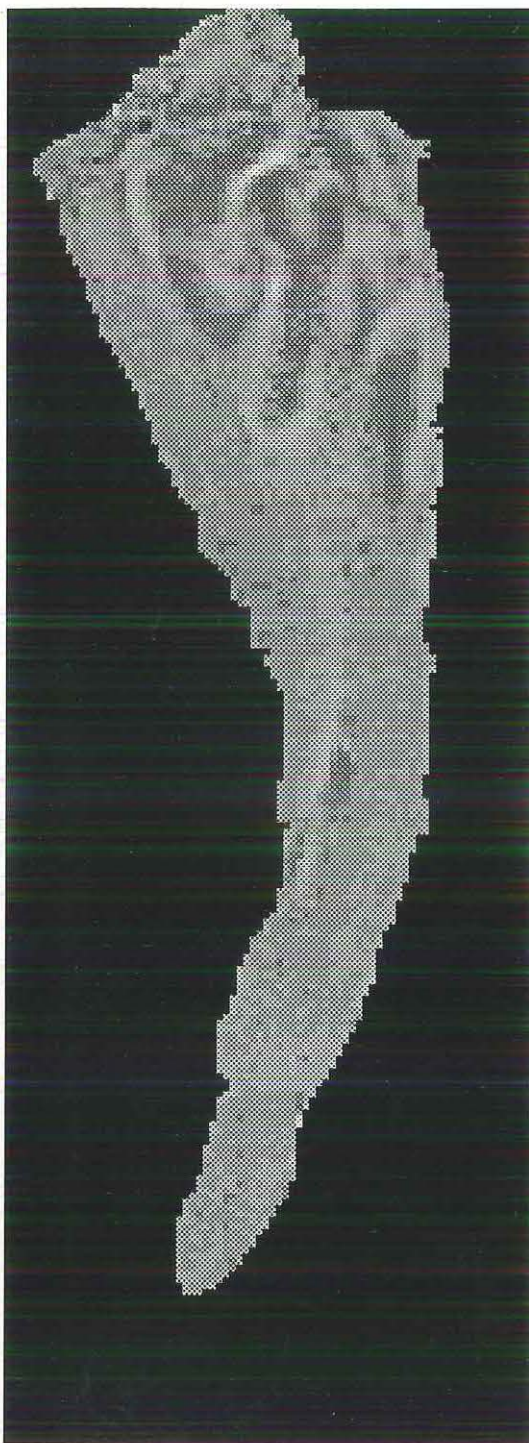


a) Brightness image representing the depth differences between 1986 and 1987 surveys of Cambridge Gulf (Wyndham) harbour.

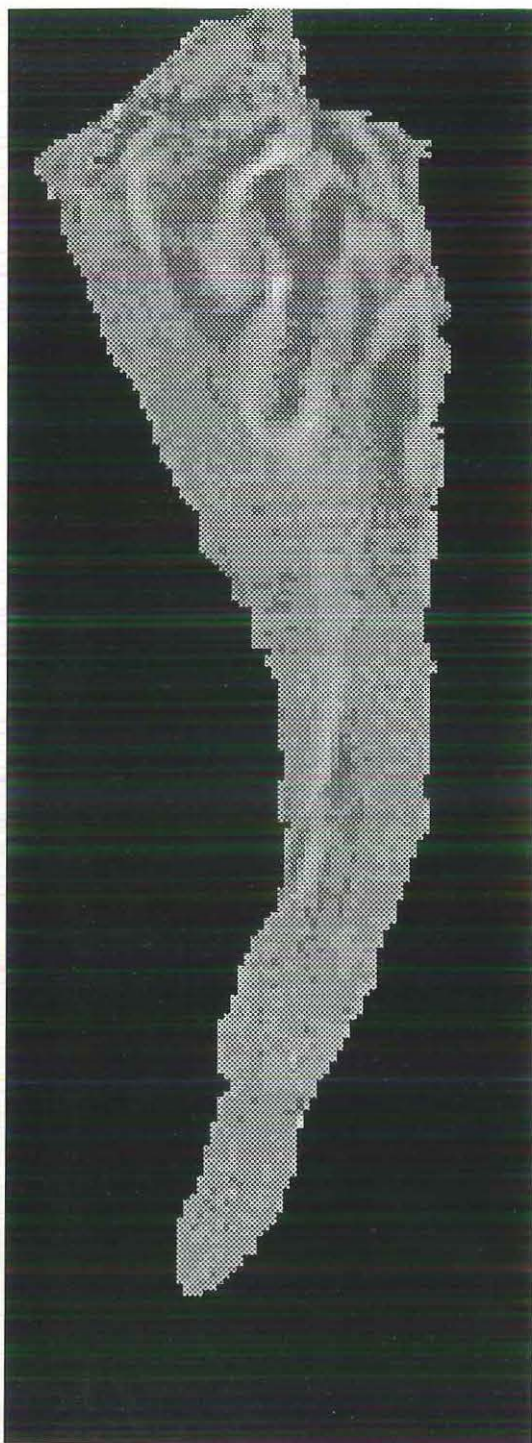


b) Brightness image representing the depth differences between 1986 and 1988 surveys of Cambridge Gulf (Wyndham) harbour.



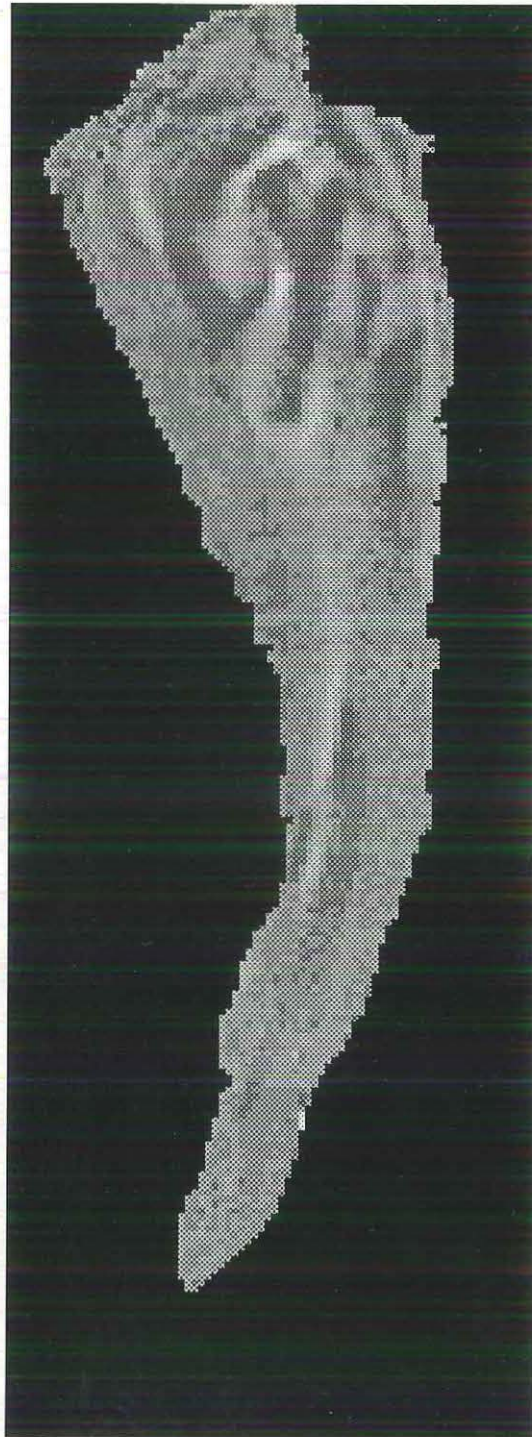


c) Brightness image representing the depth differences between 1986 and 1989 surveys of Cambridge Gulf (Wyndham) harbour.

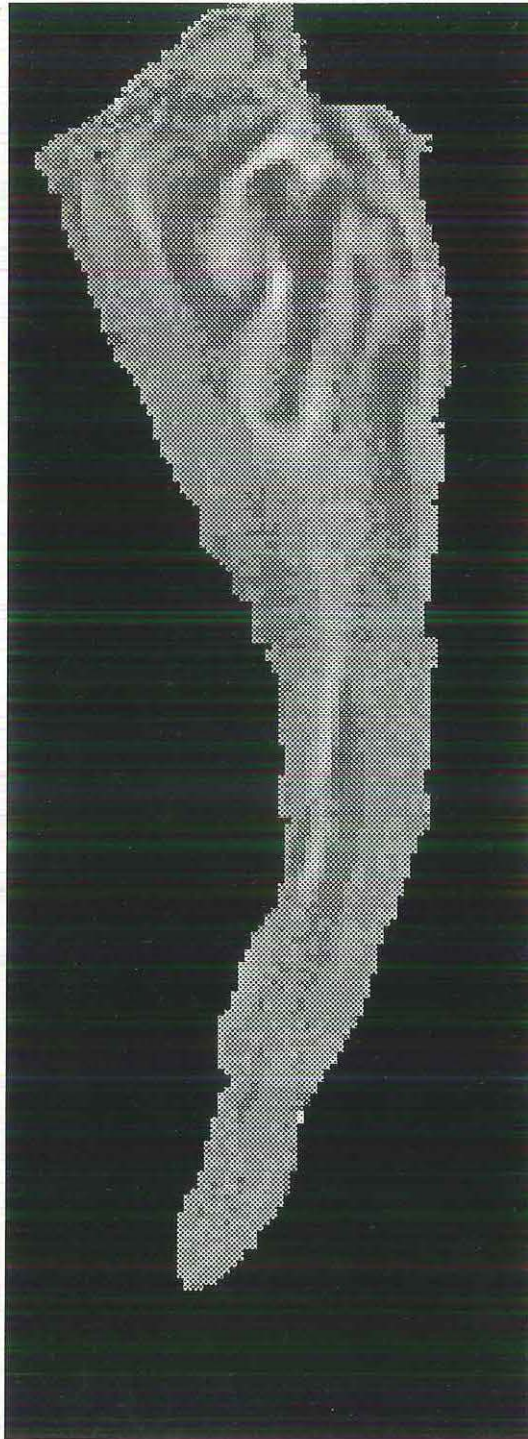


d) Brightness image representing the depth differences between 1986 and 1990 surveys of Cambridge Gulf (Wyndham) harbour.





e) Brightness image representing the depth differences between 1986 and 1991 surveys of Cambridge Gulf (Wyndham) harbour.



f) Brightness image representing the depth differences between 1986 and 1992 surveys of Cambridge Gulf (Wyndham) harbour.

*Figure 12a)..f):* Brightness images representing the depth differences between 1986 and 1987, 1986 and 1988, .. 1986 and 1992 surveys of Cambridge Gulf (Wyndham) harbour.

## Appendix C.

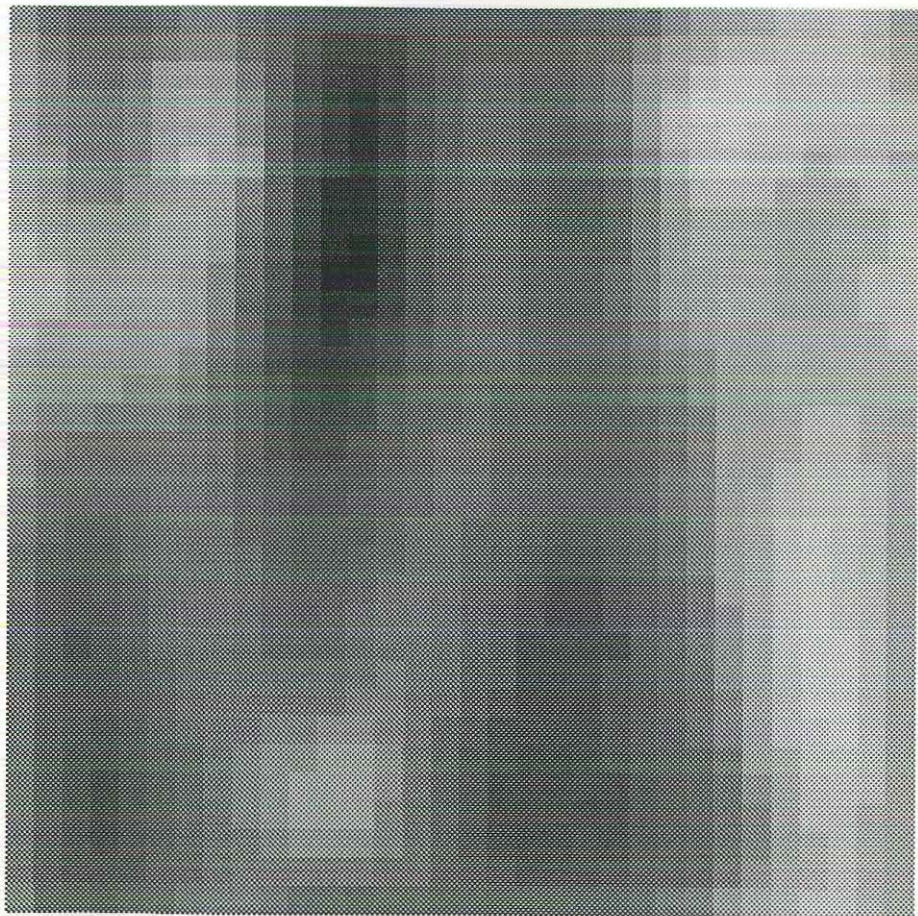
This appendix shows a series of brightness images displaying the changes in a patch of the depth data of Cambridge Gulf (Wyndham) over a period of seven years (see Figure 13). The direction of water flow is from the bottom to the top of the image.

This set of images was created by "clipping" out an area showing movement (32 by 32 pixels). The data was smoothed, to reduce noise before the optical flow calculations were performed. The smoothed data was transformed into images by assigning brightness values to represent depth values within the data, with darker pixels representing deeper parts in the data. Black indicates the missing data value 999.9. White indicates points above the water level.

To help the viewer gain an understanding of the changes over time, the images have been printed with the same position and size on consecutive pages. To gain an understanding of the motion, riffle the images within Figure 13. This Appendix varies from the previous two in that the images are printed closer to the edge of the page. This allows the viewer to turn the page less and helps get a better continuance of the images.

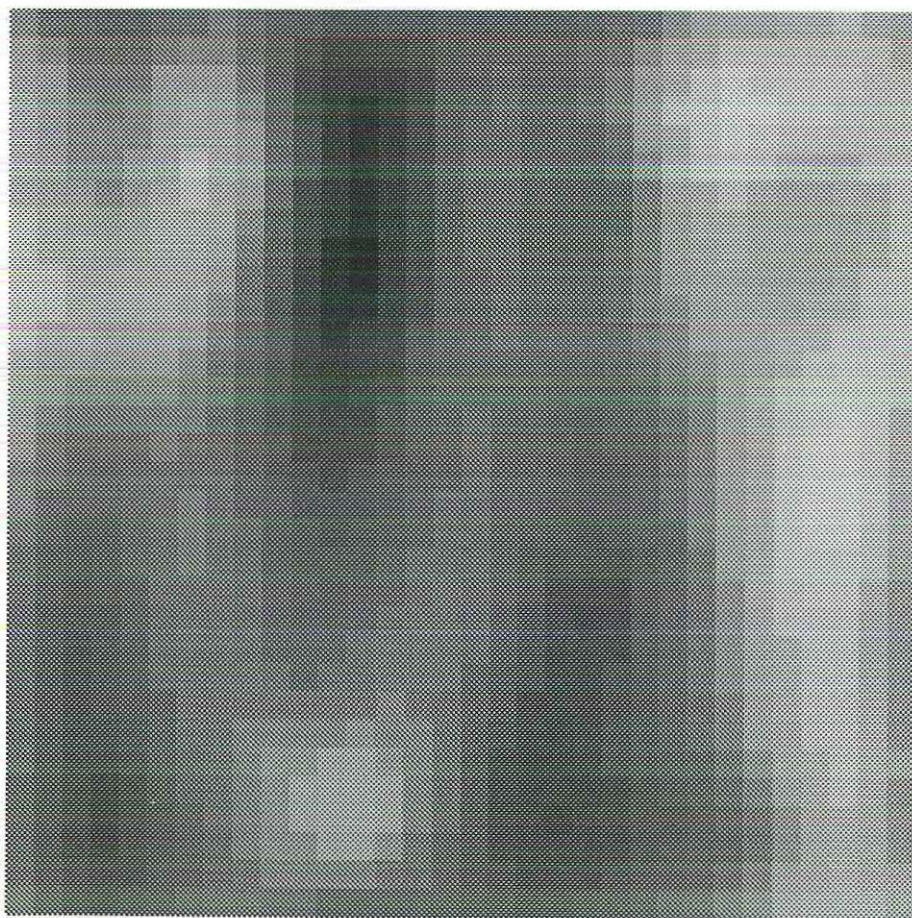
Appendix D contains the results of the optical flow calculation and visualisation performed on this set of images.





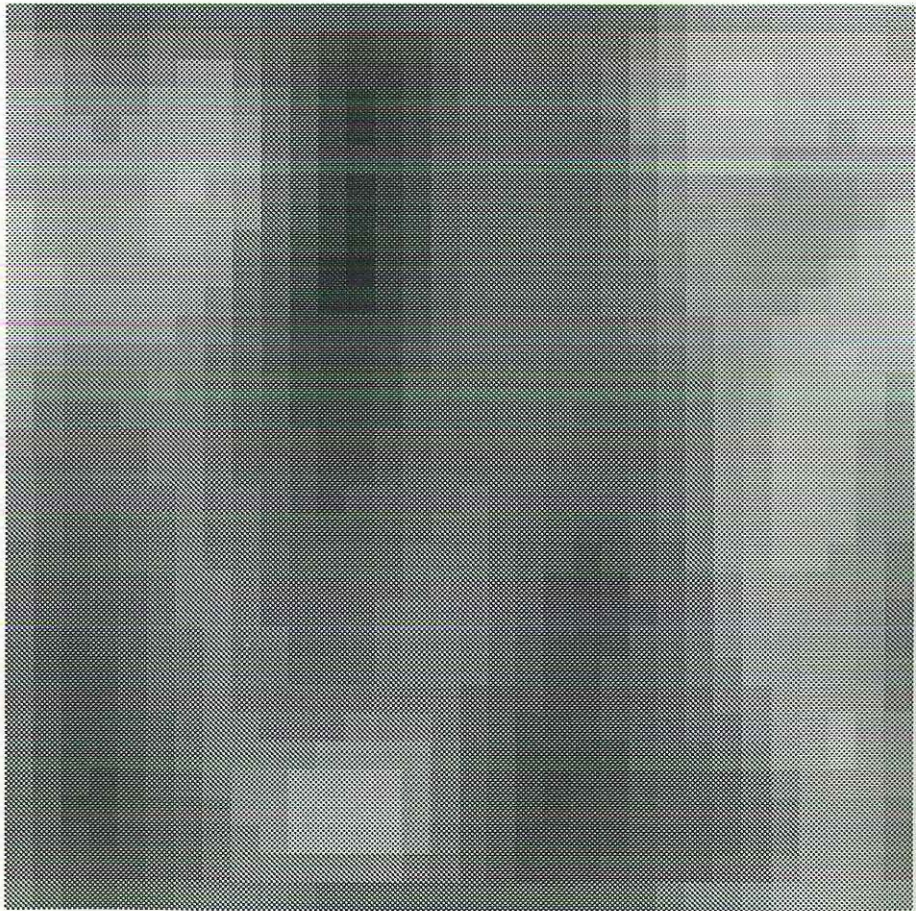
a) Brightness image of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour - 1986.





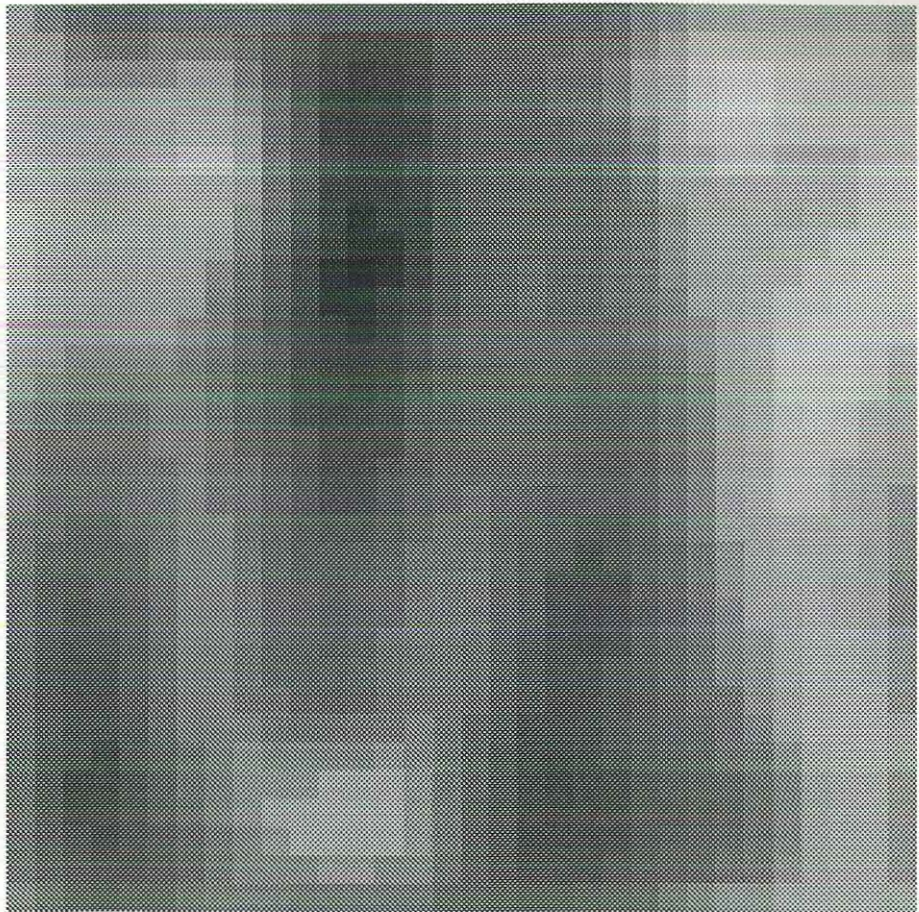
b) Brightness image of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour - 1987.





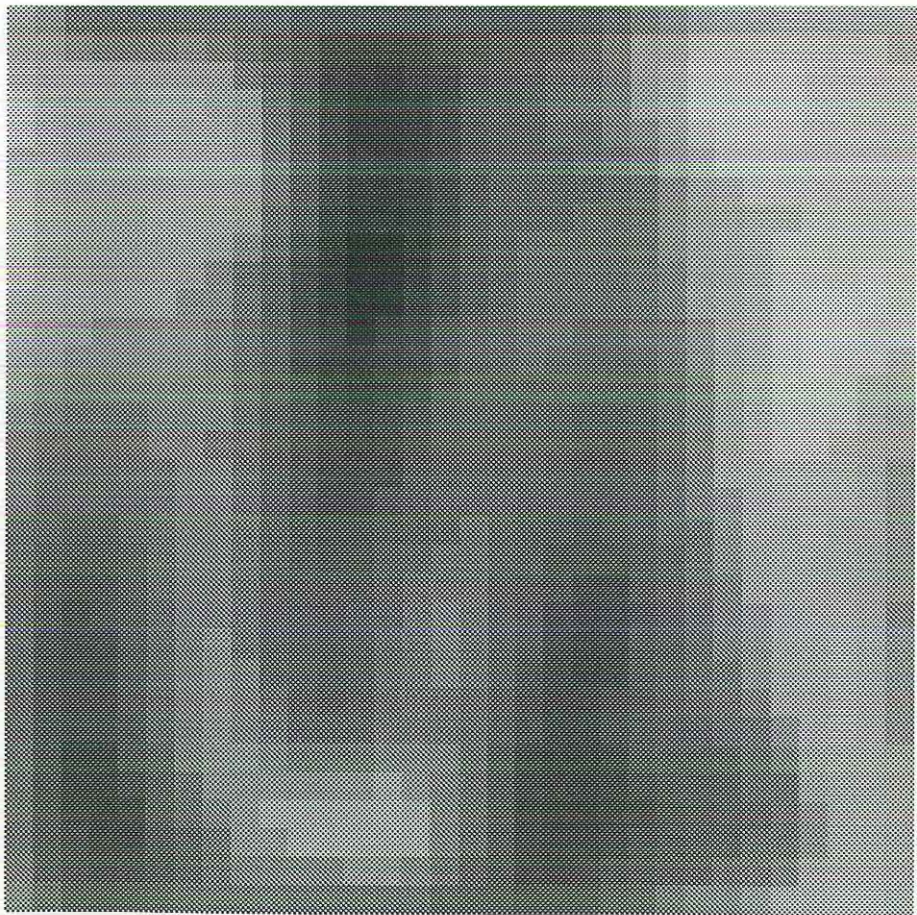
c) Brightness image of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour - 1988.





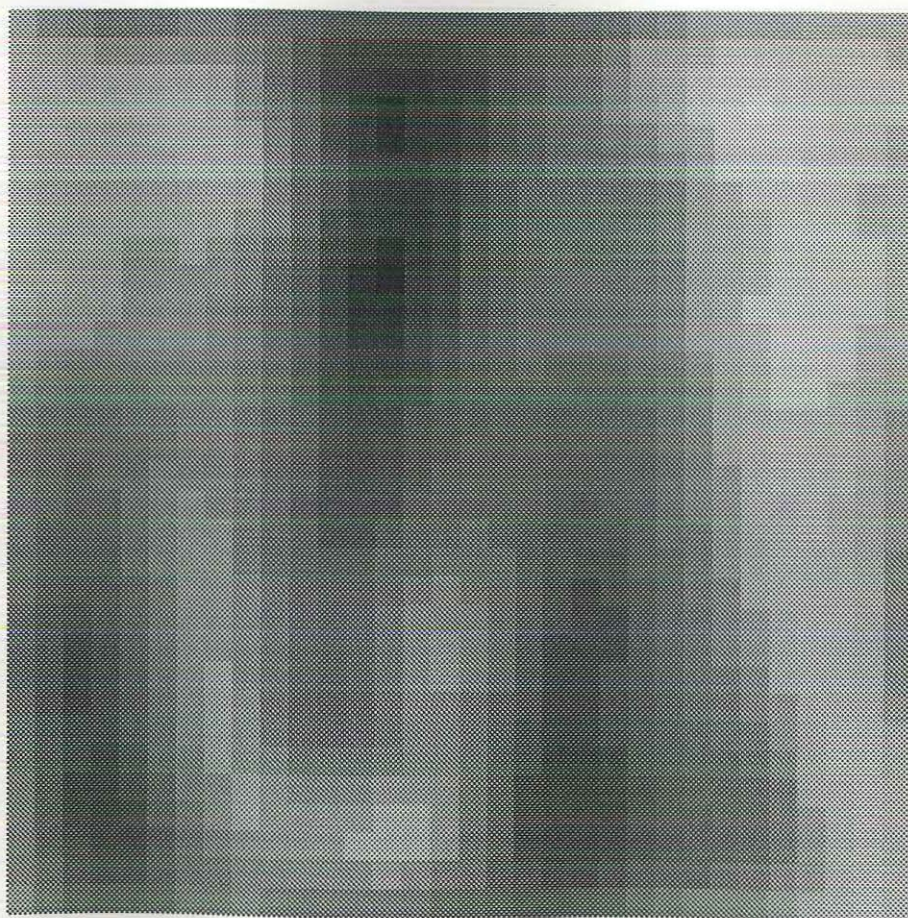
d) Brightness image of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour - 1989.





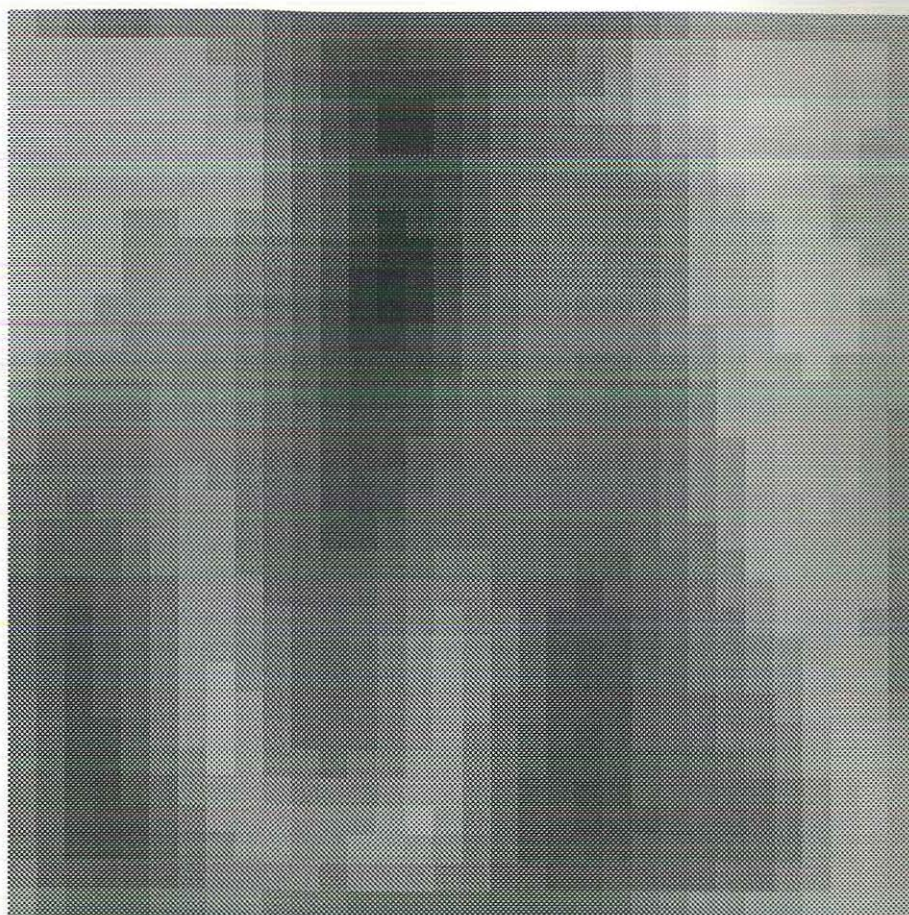
e) Brightness image of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour - 1990.





f) Brightness image of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour - 1991.





g) Brightness image of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour - 1992.

*Figure 13a)..g):* Brightness images of a window from Figure 11, highlighting the changing depth of Cambridge Gulf (Wyndham) harbour for years 1986 to 1992.

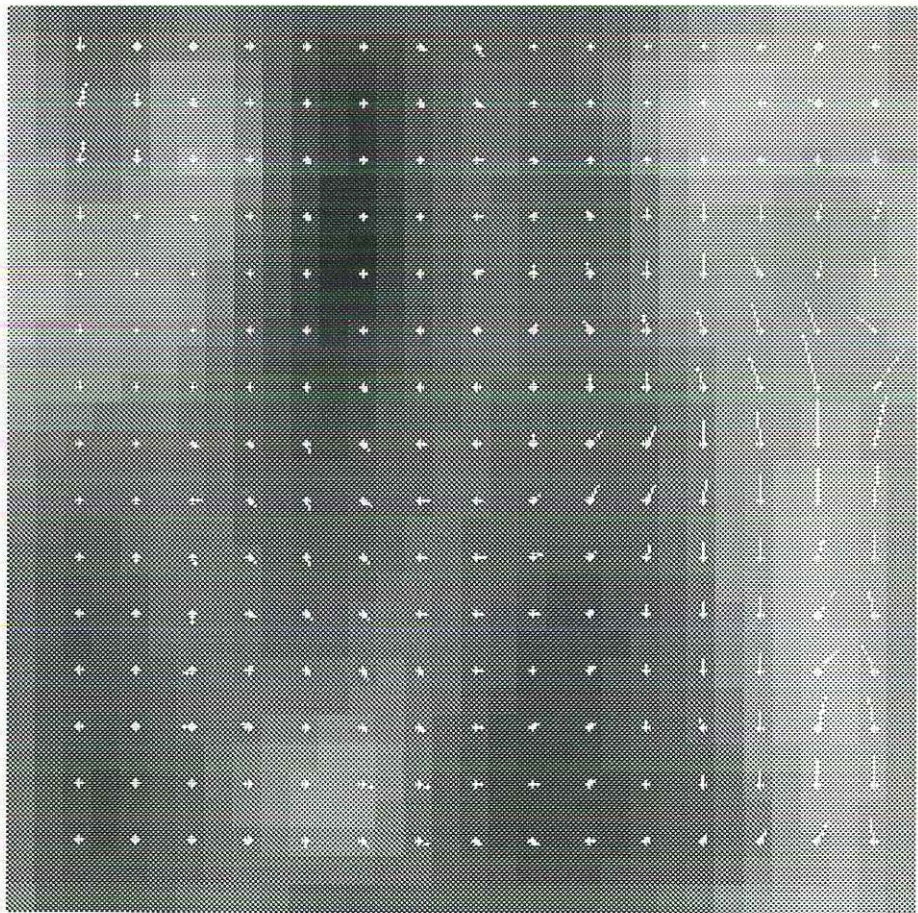
## **Appendix D.**

This appendix shows a series of optical flow needle diagrams for the patch of Cambridge Gulf (Wyndham) shown in Appendix C. The optical flow velocities were visualised over the original brightness images to aid in the tracking of features. The point of origin for each needle is indicated by a '+'. The direction of water flow is from the bottom to the top of the image.

To help the viewer gain an understanding of the optical flow changes over time, the needle diagrams have been printed with the same position and size on consecutive pages. To gain an more thorough understanding of the motion, riffle the images within Figure 14.

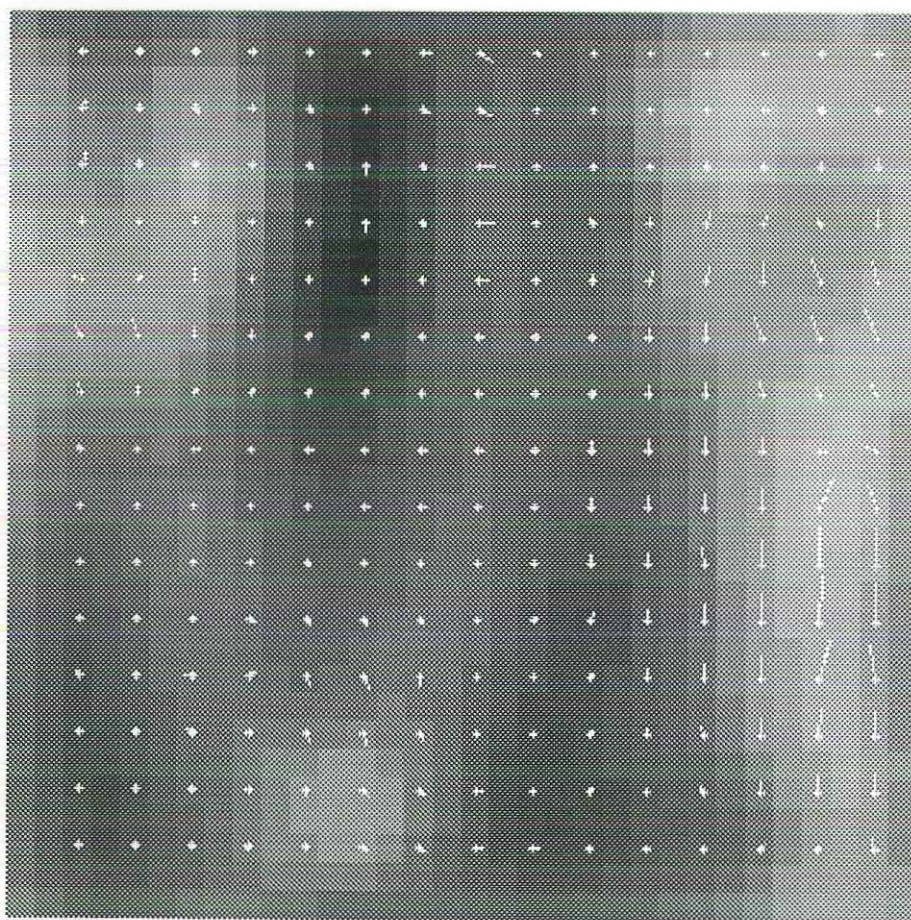
The images have been printed in the same position of as Appendix C to aid in any comparison process.





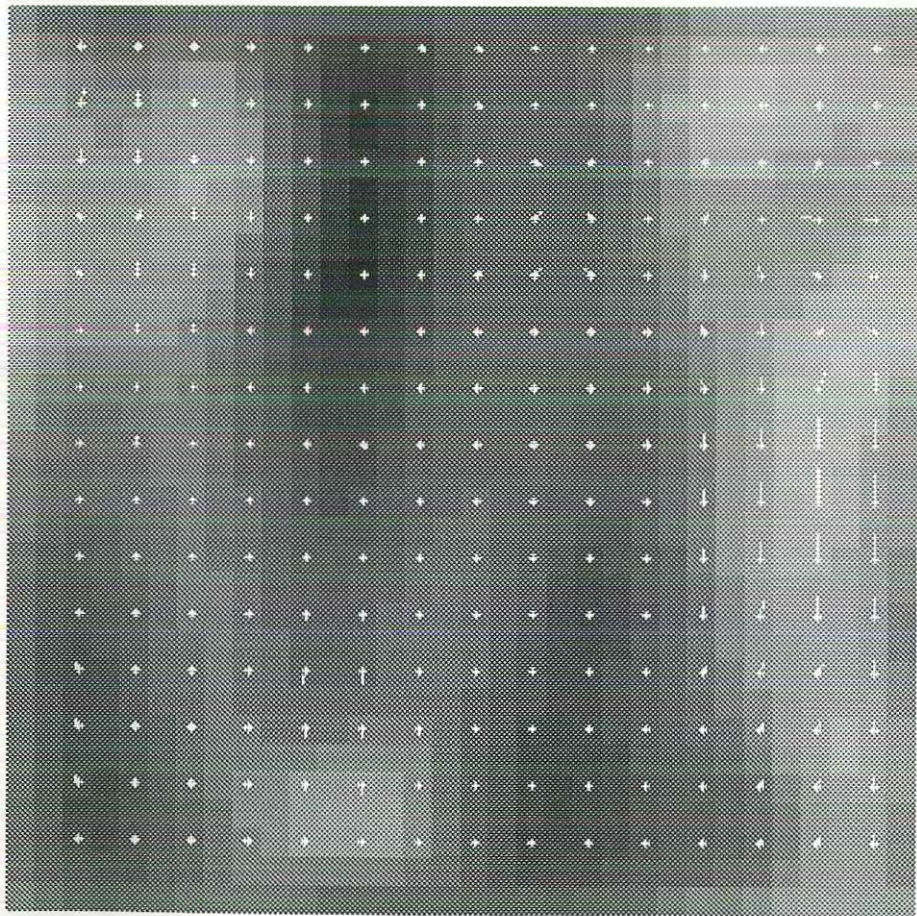
a) Needle diagram showing the 1986 to 1987 optical flow superimposed over the 1986 brightness image from Figure 13.





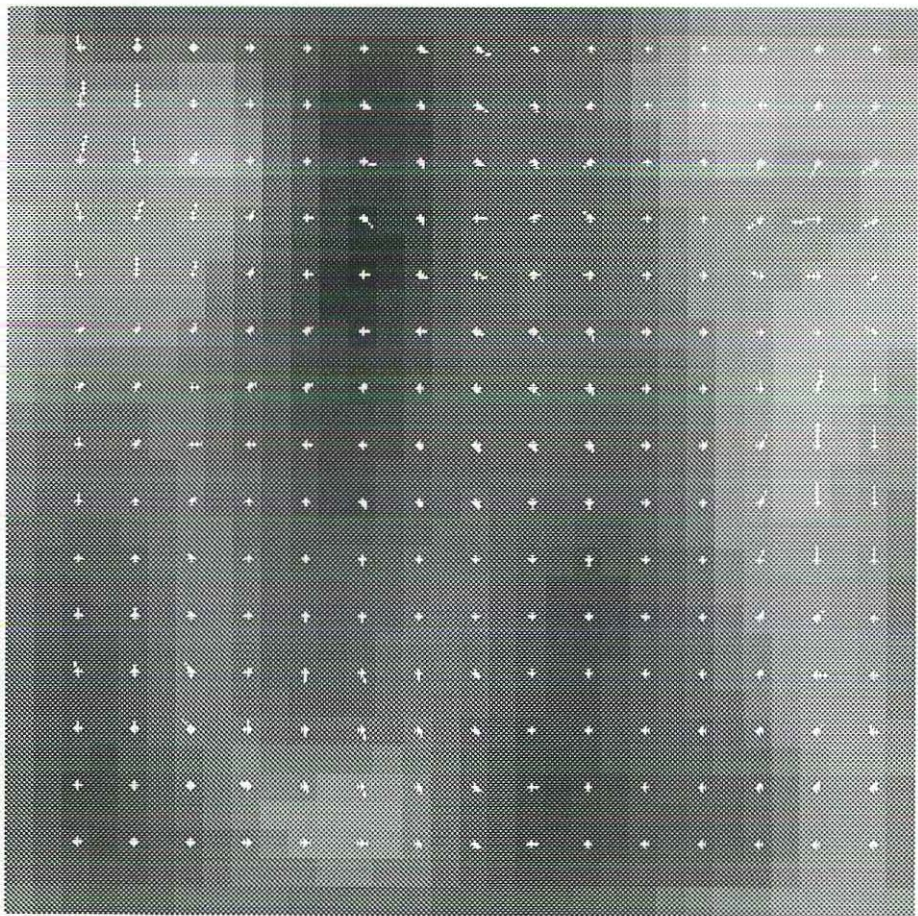
b) Needle diagram showing the 1987 to 1988 optical flow superimposed over the 1987 brightness image from Figure 13.





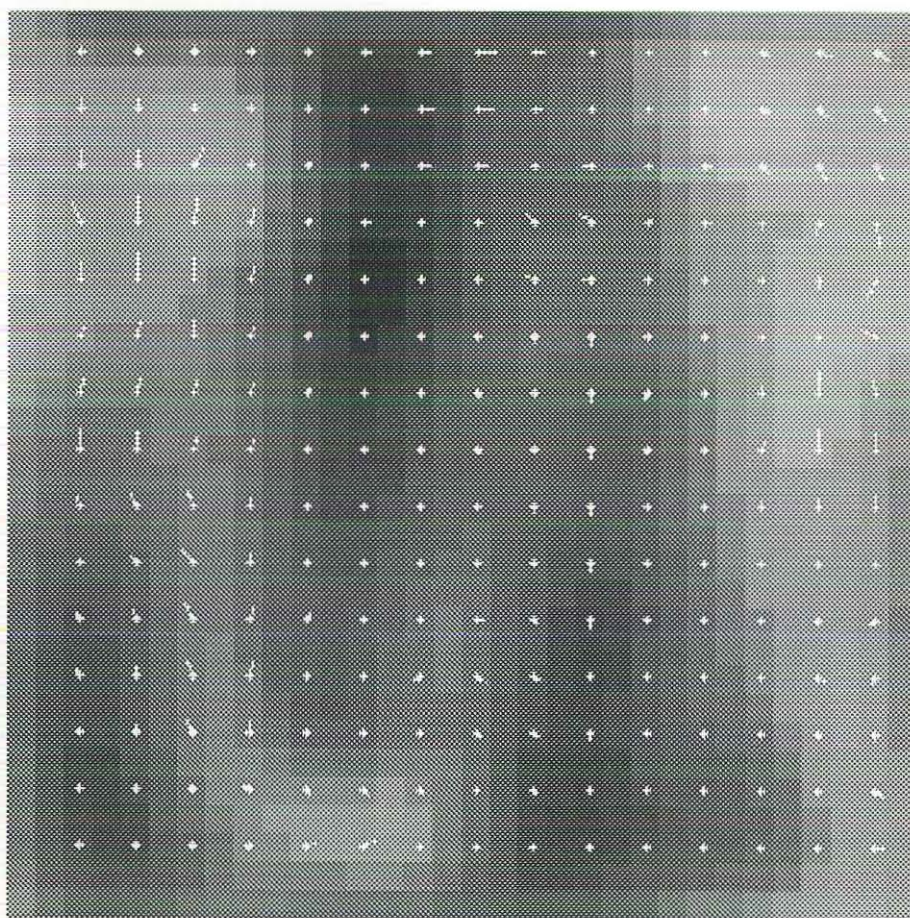
c) Needle diagram showing the 1988 to 1989 optical flow superimposed over the 1988 brightness image from Figure 13.





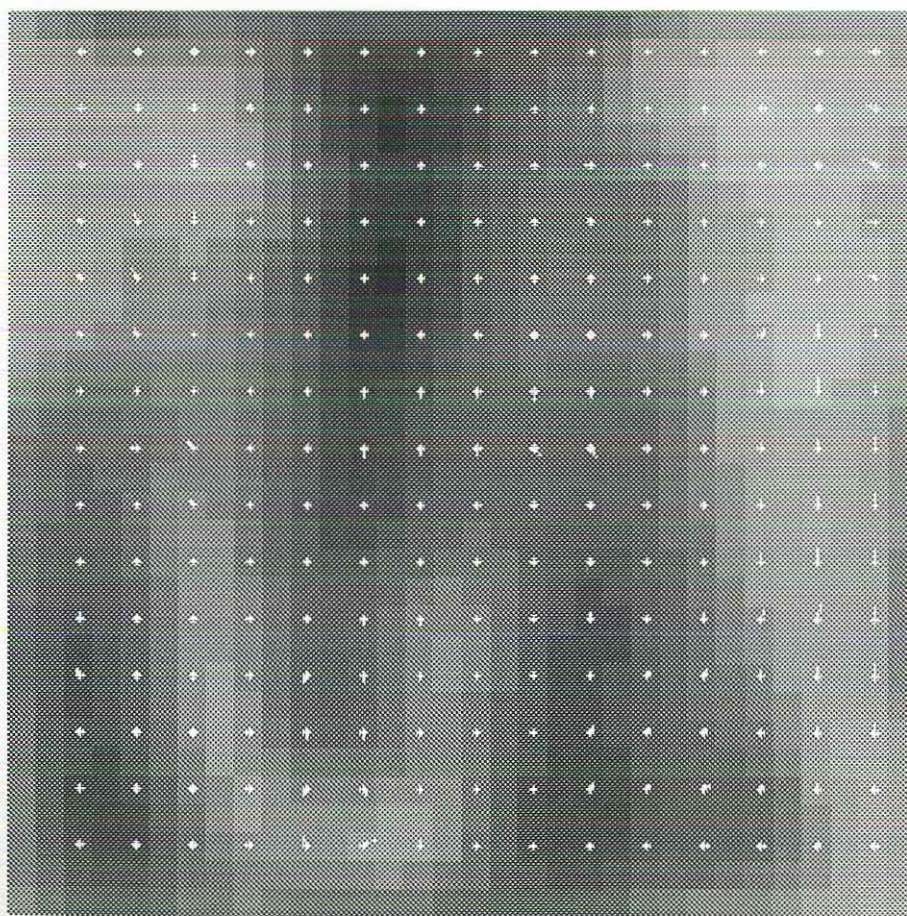
d) Needle diagram showing the 1989 to 1990 optical flow superimposed over the 1989 brightness image from Figure 13.





e) Needle diagram showing the 1990 to 1991 optical flow superimposed over the 1990 brightness image from Figure 13.





f) Needle diagram showing the 1991 to 1992 optical flow superimposed over the 1991 brightness image from Figure 13.

*Figure 14a)..f).* Needle diagrams showing the 1986 to 1987, 1987 to 1988, .. and 1991 to 1992 optical flow superimposed over the 1986, 1987,.. 1991 brightness images from Figure 13.